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Fuzzy Logic Controlled Microturbine Generation System for Distributed Generation

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Abstract

The microturbine based Distributed Generation (DG) system are becoming the popular source of power industries due to their fuel flexibility, reliability and power quality. The microturbine generation (MTG) system is a complicated thermodynamic electromechanical system with a high speed of rotation, frequency conversion and its control strategy. In spite of several techniques to control high speed of microturbine is not accurate and reliable due to their anti-interference problem. To resolve the anti-interfacing problem, this paper investigates the fuzzy logic based speed governor for a MTG system as an alternative to nominal PI or lead-lag based controller. The development of fuzzy logic based speed governor includes input and output membership function with their respective members. The load variation on MTG system is performed using conventional and fuzzy logic controller, implemented in Matlab/simulink and results are compared with each other. The simulation result shows that, the performance improvement of fuzzy logic governor over a nominal governor based MTG system.

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Keywords; Microturbine PMSM, Power Converter, Fuzzy logic.

1. Introduction

Distributed Generation (DG) is predicted to play an increasing attention in the electric power system of the near future. DG is limited size of generation (25kW to 1MW) and interconnected at the substation, distribution feeders or consumer load levels [1]. The microturbine generation (MTG) system is a typical and practical system of DG source, because of its small scale generation with fuel flexibility, reliability

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and power quality. It has been applied in various fields, such as peak power saving, co-generation, remote and premium power applications [2]. The MTG system composed of microturbine as a prime mover, permanent magnet synchronous machine (PMSM), power interfacing circuit for frequency conversion between generation and load. A microturbine is thermodynamically complex mechanical system cannot be modelled accurately and it is difficult to control the speed [2]. A microturbine is integrated with PMSM produces high frequency AC power, where the operating speed ranges generally between 50,000 to 120,000 rpm. The power produced at the generator is around 1 k to 2 kHz of frequency, this high frequency AC power is converted to DC then inverted back to 50 or 60Hz AC power using suitable converter and inverter [3]. The nonlinear controlled methods based on model cannot solves the various control problem on MTG system, some advance control methods have been applied such as incremental fuzzy PI controller, fuzzy PID controller and neural network controllers. Controlled algorithm based on fuzzy logic have been implemented in many processes the application of such control techniques has been motivated by the following reasons, 1) it improves the robustness over a conventional linear control algorithm, 2) Simplified control design for difficult system model 3) Simplified implementation[4]. This paper presents a fuzzy logic controlled speed governor in place of conventional transfer function governor of a microturbine. The load variation on the MTG system is made to obtain the performance of microturbine used as MTG system.

1.1 Microturbine

Microturbines are smaller version of heavy duty gas turbines compact in size and components like compressor, heat exchanger, burner and turbine. Basically there are two types of microturbines, classified based on construction and location of its components. One is a high speed single shaft design with compressor and the turbines are mounted on the same shaft usually the PMSM is use to generate the electrical power. Another is split shaft design that uses a power turbine rotating at 3600 rpm and a conventional generator (usually induction generator or synchronous generator) connected via a gearbox [6]. The microturbine system presented in this paper is based on gas turbine model presented by W I Rowen[5] which was successfully adopter as microturbine generation(MTG) system by Huang Wei[6] connected in parallel to the microgrid, and used as DG system by Gaonkar[7] and Guda S R[8] in isolated mode. The turbine model was proposed by W I Rowen[5] is to be adopted as single shaft microturbine with fuzzy logic speed governor implemented in MATLAB/Simulink is shown in Fig.1, and the same is used as prime mover for the MTG with PMSM and power electronics circuit interfacing system shown in Fig.2.

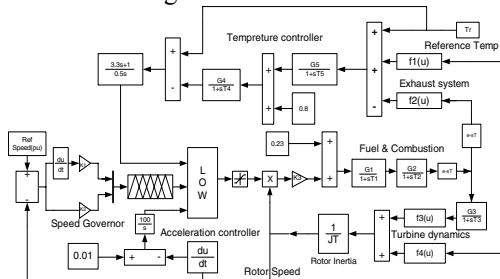


Fig.1. Fuzzy logic controlled microturbine

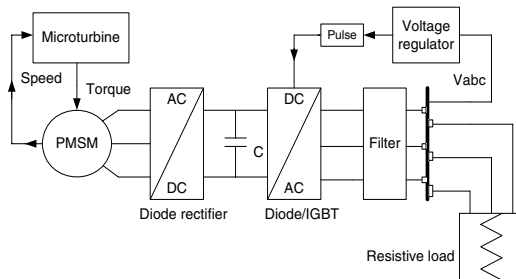


Fig.2 Fuzzy logic controlled MTG system

The linear pattern is utilizes as generator model applicable for transient analysis and the model comprises temperature controller, fuel control, turbine dynamics, speed governor and acceleration controller blocks [7]. The speed governor for a microturbine can be divided into droop regulation and non-drop regulation, which is utilized and designed for the purpose of adopting the requirement of different load characteristics.

Speed controller is usually modelled using lead-lag transfer function or by PID controller. In this work a fuzzy logic based governor has been used as speed and change in speed are input membership function, regulated speed as output membership function. The membership function can be adjusted so that the governor can act with droop or as isochronous governor [7][8]. The fuel flow is controlled as a function of Vce are shown in a series of blocks including the valve position and flow dynamics, the output of low value selector (represented by Min in MATLAB/Simulink) is the lowest of the three inputs and results in the amount of fuel to the compressor-turbine, and Vce represents the final amount of fuel demand for that particular operating point and is an input to the fuel system [6][8]. The slow dynamics performance of the MTG system is focused here based on the simplified model built with an assumption, i.e. MTG system is operating under normal condition by neglecting the fast dynamics of microturbine (start up, shut down, internal faults, sudden loss of power etc). In addition to that the proposed model employees per unit system to represent the microturbine as its control system with expectation of temperature, each important control block is discussed as subsection in [7] [8]. The model presented in this paper is concentrates on slow dynamics of MTG system.

1.2 Permanent Magnet Synchronous Machine (PMSM) and Power Electronics Interface Circuit.

The MTG system uses high speed PMSM for conversion of mechanical energy to electrical energy. The model adopted for MTG system is, a two pole PMSM with a non-salient rotor. At 1600Hz frequency, the rated power generated by the machine is 60KW and its terminal line to line voltage is 480V. The electrical and mechanical component of the generator are represented by two second order state space models, meanwhile the DC field winding of the rotor is replaced by a permanent magnet, the main advantage of eliminating of field copper loss, a higher power density, lower rotor inertia, and roughed in construction of the rotor. The analyses of PMSM by dq0 axis for a balanced dq axis equation are shown in [12], and the parameters of high speed PMSM are as per the Table.2.

The high frequency AC power generated by the PMSM is rectified to DC and then inverted back to 50 or 60Hz AC, after elimination of harmonics it is feed to the general use. The power conditioning is the critical component in a single shaft microturbine MTG system, especially in matching turbine output to the required load [7]. The power conditioning circuit consists of three phase simple diode bridge rectifier, voltage source inverter (VSI) and inductance, capacitance (LC) filter. The IGBT inverter uses pulse width modulation (PWM) at carrier frequency of 2000 Hz and sampling time of 2 μ s, the filtered DC voltage is applied to an IGBT two level inverter generating 50Hz, and control scheme are regulated at 480 V rms.

PMSM Parameter	
Number of poles	P=2
Maximum speed	Nmax =100krpm
Moment of inertia	J=7e-4kgm2
Stator resistance	Rs=0.08
d & q inductance	Ld=Lq=286 μ H
Rated power	Pn = 30kW

Table 2. PMSM parameters

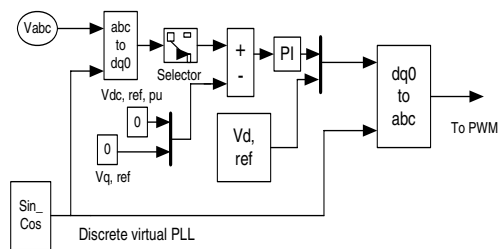


Fig.3 Voltage control scheme of VSI

The load voltage is regulated at 1 pu by a PI voltage regulator using abc_to_dq and dq_to_abc transformation. The output of voltage regulator is a vector containing the three modulating signals used by the PWM generator to generate six IGBT pulses. The discrete three phase PWM pulse generator is available in the discrete block library of Matlab/Simulink.

2. Fuzzy logic

Fuzzy logic controller is rule based controller where a set of rules represents a control decision mechanism to correct the effect of certain cause used for generation systems. In fuzzy logic, the linguistic variables are expressed by fuzzy sets defined on their respective universe discourse, to overcome the difficulties of soft controlling fuzzy logic found to be effective alternating to conventional control techniques[9]-[10]. The configuration of fuzzy logic based system into four parts they are,

- Fuzzification, Knowledge Base, Interface Mechanism and Defuzzification.

The lead lag transfer function compensator is replaced by the equivalent fuzzy logic based speed governor, the design of PI-like fuzzy knowledge base controller works on the area control error (ACE) and change in area control error (ΔACE) is considered as input to the fuzzy logic controller. For the automatic generation control problem the input to fuzzy controller for *i*th area at a particular instant are $ACE_i(t)$ and $\Delta ACE_i(t)$. The input and output are transformed into linguistic variables as VHS: Very High Speed, HS: High Speed, NC: No Change, NS: Normal Speed, LS: Low Speed, VLS: Very Low Speed, LN: Large Negative, N: Negative, P: Positive, LP: Large Positive, VL: Very Low, L: Low, Z: Zero, H: High, VH: Very High- respectively. All the variables of ACE, ΔACE and ΔU are considered in a symmetrical triangular membership function. The membership function of ACE over the operating range of minimum and maximum values of ACE is shown in Fig.4 (a)(b) and (c). The membership function would perform a mapping from the crisp values to a fuzzified value, One such particular crisp input ACE is converted to fuzzified value i.e. $0.8/VHS + 0.2/HS$ where 0.8 and 0.2 are membership grade membership function.

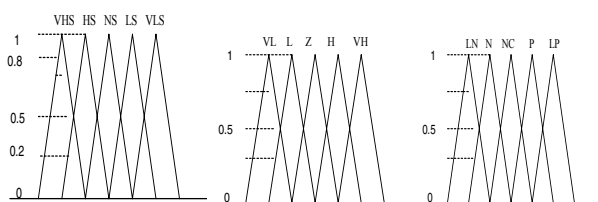


Fig.4 a) Speed b) Change in speed c) Reg. speed

Speed	VL	L	Z	H	VH
VLS	LN	LN	LN	N	NC
LS	LN	LN	N	NC	P
NS	LN	N	NC	P	LP
HS	N	NC	P	LP	LP
VHS	NC	P	LP	LP	LP

Table. 2 Fuzzy logic table

Corresponding to the linguistics variables VHS and HS in fuzzy system a membership grades are zero for all other linguistic values except VHS and HS. Here the crisp value input to the system will be converted to fuzzified value considering several membership grades corresponding to each linguistic variable. Same way the other input of ΔACE and ΔU are fuzzified. The output of the inference mechanism is a fuzzy value, and hence it is necessary to convert the fuzzy value to (crisp) real value sine, the physical process can't deal with fuzzy values. This operation which is inversely fuzzified is known as defuzzification. The well known centre of defuzzification method has been used for its simplicity. The major drawback of Mean of Maximum (MOM) method is that it does not use all the information converted by the fuzzy command and hence it becomes difficult in generating commands that run the system smoothly.

$$\Delta U = \frac{\sum(\text{Membership } 1/p * \text{Output correspond ing } 1/p)}{\sum(\text{Membership of } 1/p)} \quad \Delta U = \frac{\sum \mu_j * U_j}{\sum \mu_j}$$

ΔU is determined using the centre of gravity method μ_j is the membership value of the linguistic variables recommending the fuzzy control action, U_j is the precise numerical value corresponding to the fuzzy control action. The ΔU obtained from (9) is added with the existing previous signal to obtain the actual output signal U which is given to the microturbine [11].

3. Results and discussion

The MTG system is simulated using both conventional and fuzzy logic governor microturbine. Initially the MTG system is driving a 10kW, 380 volts electrical load. Due to the small inertia and damping in the microturbine without considering the complex and non-linear start-up processes, the stable operation cannot be considered for first 25 seconds. Based on this consideration dynamic simulations have been performed to evaluate the response of the MTG system. Initially the fuel demand is 0.58 pu for 10kW load. At $t=30$ secs the load is increased to 10kW and the fuel demand is increased to 0.75 pu. Again at $t=60$ secs a 10 kW load is increased and the fuel demand is also increase as shown in Fig.5 (a). The shaft torque varies as the load varies on MTG system, this variation in the torque at interval of $t=30, 60$ and 90 secs is shown in Fig.5 (b). The speed and torque are inversely proportional to each other, hence the decreasing and increasing in the speed at $t=30, 90$ secs and $t= 90$ secs respectively as shown in Fig.5(c). The power developed in the turbine is also proportional to the demand power, the turbine power varies as the demand power varies as shown in Fig.5 (d).

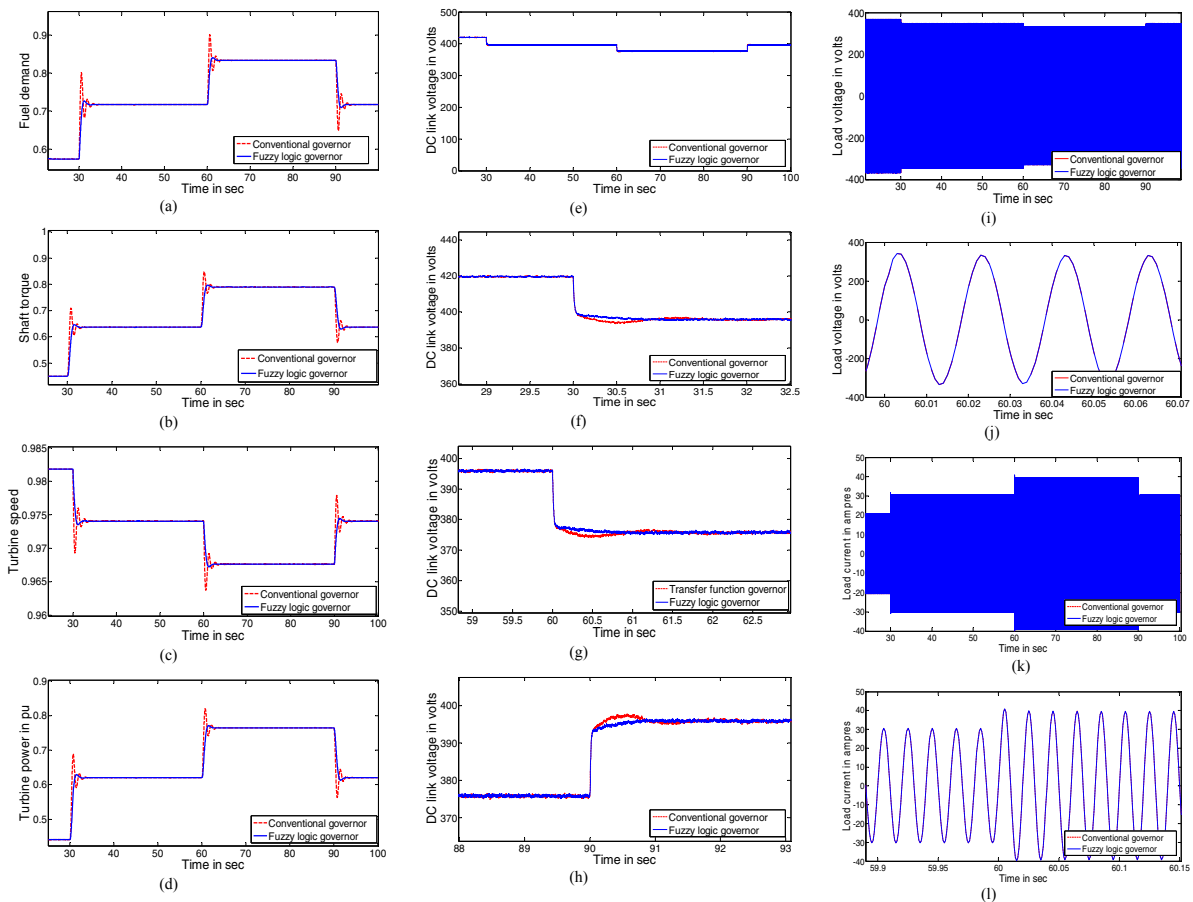


Fig. 5(a) Fuel demand in pu, (b) Shaft torque in pu, (c) Turbine speed in pu, (d) Turbine power in pu, (e) DC link voltage in volts, (f) DC link voltage at $t=30$ sec,(g) DC link voltage at 60 sec, (h) DC link voltage at 90 sec,(i) Load voltage Vac (j) Sinusoidal voltage in volts, (k) Load current in amps, (l) Variation in load current.

The DC link voltage V_{dc} , varies as the load varies at interval of $t=30, 60$ and 90 secs on the MTG system is shown in Fig.5 (e). The variation of DC link voltage at interval of $t=30, 60$ and 90 secs and comparison of governor performance are as shown in Figs.5(f),5(g) and 5(h) respectively. The variation of load AC voltage V_{ac} with variation of load on the DG system is shown in Fig.5 (j) and the sinusoidal voltage is shown in Fig.5(j). The load current I_{ac} is shown in Fig.5(k) and sinusoidal current waveform is shown in Fig.5(l). During every interval of load variation, there is a variation in demand power, i.e. at $t=30, 60$ and 90 secs the transients are formed in case of conventional govern but are minimized in fuzzy logic governor. These transients are causing an effect of power quality in the electrical system. Thus these are minimized by using fuzzy logic based governor and power quality can be improved.

Conclusion

This paper replaces the conventional lead-lag governor by fuzzy logic governed for a microturbine and compares the performance of those two governors and conformed that the fuzzy logic governor is having less transients on each load variation on the microturbine based MTG system. Then fuzzy controlled microturbine is connected to MTG system via PMSM and power interfacing circuit to the load. The performance of fuzzy logic based governed MTG system is obtained and there is an improvement of the fuzzy controller is high robust against the interference. It is easy for non mathematical and engineering implementation. The simulation results are obtained in MATLAB/Simulink environment and shown that fuzzy controlled microturbine can ensure the desirable dynamic response of the MTG system and has ability of the anti-interfacing as a distributed generation system. The use of fuzzy logic based controller in the microturbine will have the positive impact on power quality in the electrical distribution system.

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