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IMPROVEMENT OF OUTPUT POWER QUALITY OF A MICROTURBINE-GENERATOR BY USING MATRIX CONVERTER INTERFACE APPLIANCE

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Abstract— ***Microturbine generator is appropriate for dissimilar distributed generation applications. Due to its high speed, it is necessary to use a frequency converter to deliver the power at 50/60Hz. In this method, application of Matrix Converter as microturbine-generator interface converter is addressed. In this way, the interface converter becomes more compact due to omission of dc link capacitor Also, it is shown by the simulation results that by using matrix converter, quality of the output voltage is improved.***

Keywords— Microturbine Generator, Matrix Converter, PMSG

I. INTRODUCTION

In recent years, application of Distributed Generation (DG) sources has increased drastically. Micro turbine-Generator (MTG) is well appropriate for various distributed generation applications, because it can be connected in parallel to supply larger loads, can provide reliable power and has low-emission.

MTGs have the rated power from 30 to 250kW, generating electricity in ac, and they can be installed in inaccessible conditions or coordinated with the electrical utility. The main distinctiveness of MTG can be summarized in low maintenance, capacity of operation with liquid and gas fuels (including natural gas) and small area required for installation [2].

MTGs are available as single-shaft or split-shaft units. Single-shaft unit is a high-speed synchronous machine with the compressor and turbine mounted on the same shaft. While, the split-shaft design uses a power turbine rotating at 3000rpm and a conventional generator connected by means of a gear box for speed multiplication [1]. In this paper, the single-shaft structure is considered. Single-shaft MTGs are typically composed of gas turbines, electric power generators (usually a permanent magnet synchronous generator), frequency converters (interface converters), and protection and control systems(Fig)[2]. The interface converter is used to convert PMSG output voltage frequency (high frequency) to power system (50/60Hz) frequency.

The small gas-fired micro-turbines in the 25-500kW that can be mass-produced at low cost have been more attractive due to the competitive price of natural gas, low installation and maintenance costs. It takes very clever engineering and use of innovative design to achieve reasonable efficiency and costs in machines of lower output. A big advantage of these systems is small-sized because these technologies mainly use high-speed turbines(50,000-120,000RPM) with air foil bearings. Therefore, micro-turbines are one of the most promising of there newable electric generation technologies for applications today. Fig below shows a block diagram of micro-turbine system that consists of air compressor, recuperator, combustor, turbine, generator, and a PCU.

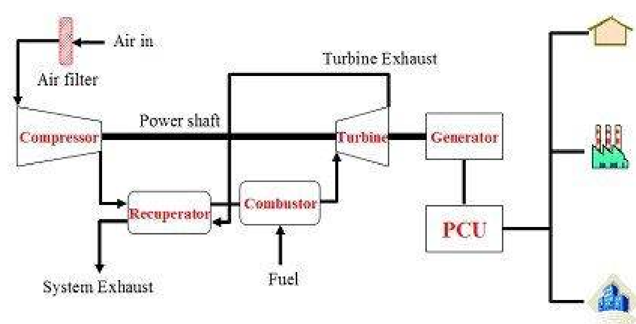

Fig 1 : Block diagram of micro-turbine generator

II. SINGLE SHAFT MTG

Fig below shows a high speed single shaft design with The compressor and turbine mounted on the same shaft along with the permanent magnet synchronous generator. The generator generates power at very high frequency ranging from 1500 to 4000Hz.The high frequency

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voltage is first rectified and then inverted to a normal AC power at 50 or 60Hz.

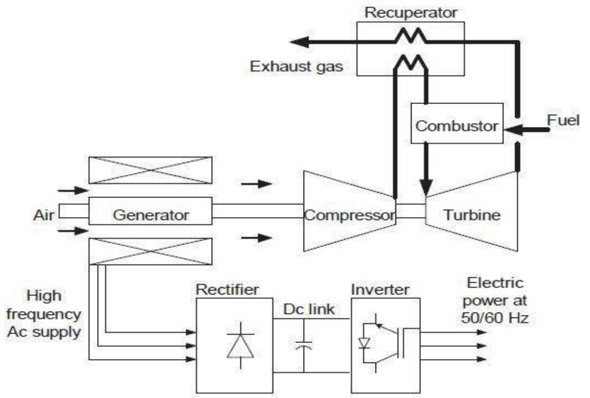

Fig 2 : Block diagram of single shaft MTG

In a microturbine, the turbo-compressor shaft generally turns at high rotational speed as high as 1,20,000rpm based on the power rating. The microturbine utilizes gas foil bearings(airbearings) for high reliability, low maintenance and safe operation. This needs minimum components and no liquid lubrication is necessary to support the rotating group. Recuperators are heat exchangers that use the hot exhaust gas of the turbine (typicallyaround 1, 200ºF) to preheat the compressed air (typicallyaround300ºF) going into the combustor. This reduces the fuel needed to heat the compressed air to turbine in let temperature. With recuperator microturbine efficiency can go above 80%.

III. MODELING OF MICROTURBINE

In this paper, the model proposed in [3,4] is considered for microturbine. The modeling of microturbine has been done in Matlab/Simulink. A scan be seen in the model is made up of speed controller, acceleration controller, temperature controller and fuel system (including valve positioned and actuator).

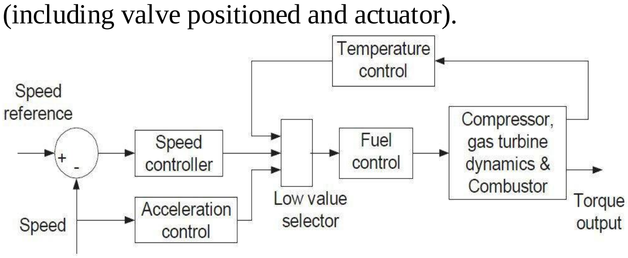

Fig 3 : Block diagram of Microturbine system with controls

Speed and Acceleration Control: The speed control operates on the speed error formed between a reference (one per-unit) speed and the MTG system rotor speed. It is the primary means of control for the microturbine underpart load conditions. Speed control is usually modeled by using a lead-lag transfer function, or by a PID controller. In this work a lead lag transfer function has been used to represent the speed controller.

Acceleration control: The acceleration control is used primarily during turbine startup to limit the rate of the rotor acceleration prior to reaching operating speed. If the operating speed of the system is close to its rated speed, the acceleration control could be eliminated in the modeling.

Fuel System: The fuel system consists of the fuel valve and actuator. The fuel flow out from the fuel system results from the inertia of the fuel system actuator and of the valve positioned.

Temperature Control: Temperature control is the normal means of limiting the gas turbine output power at a predetermined firing temperature, independent of variation in ambient temperature or fuel characteristics. The fuel burned in the combustor results in turbine torque and in exhaust gas temperature.

IV. PERMANENT MAGNET SYNCHRONOUS MACHINE

Micro turbine produces electrical power via a high-speed generator directly driven by the turbo-compressor shaft. Small gas turbines benefit in particular when the gear box that reduces the shaft speed to the speed of conventional electrical machines is eliminated, as is the case with the single-shaft designs considered here. The result is a more efficient, compact and reliable machine and the shaft speed is normally above 30,000rev/min and may exceed 100,000rev/min. High energy permanent magnets and high yield-strength materials like neodymium-iron-boron(NdBFe) or Samarium-cobalt magnets have proved very suitable for high-speed electrical machines.

In a permanent magnet synchronous machine, the dc field winding of the rotor is replaced by a permanent magnet. The advantages are elimination of field copper loss, higher power density, lower rotor inertia, and more robust construction of the rotor.

V. MATRIX CONVERTER (MC)

MC is an array of controlled semiconductor switches that connects directly the three-phase source to the three-phase load. In the other words, MC performs a direct AC/AC conversion. While, AC/AC conversion is conventionally achieved by a rectifier stage, a dc link and an inverter stage. Since, in the MC the switching is performed on sinusoidal waveforms, the output voltage quality can be better than the conventional rectifier-inverter structure. Also, there is no dc-link (large energy storage element) in MC. So, the MC is more compact compared to conventional AC/AC converters.

A common matrix converter structure consisting of 3x3 switches is shown in Fig .below. As can be seen, it connects a three-phase voltage source to a three-phase load.

The matrix converter requires a bidirectional switch capable of blocking voltage and conducting current in both directions. Unfortunately, there are no such devices currently available, so discrete devices need to be used to construct suitable switch cells. In this paper, the common-emitter back to back structure is used as bidirectional switch. Drawbacks are loss of flexibility of field flux control and possible demagnetization. The machine has higher efficiency than an induction machine, but generally its cost is higher.

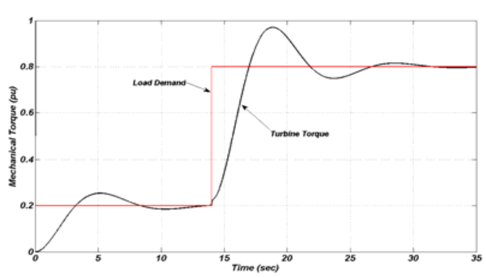

Fig 4 : Basic MC Structure

Normally, the matrix converter is fed by a voltage source and, for this reason; the input terminals should not be short circuited. On the other hand, the load has typically an inductive nature and, for this reason, an output phase must never be opened.

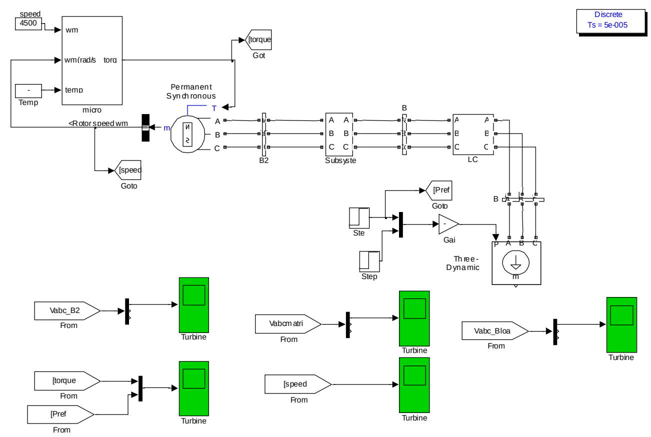

Fig 5 : Simulated System Of MTG

VI. SIMULATION RESULTS

In this section, the MTG is simulated in Matlab/Simulink. The model of PMSG available at Simulink library is used for generator simulation. This PMSG has 8poles and its rated power is 30kW.

In simulations, the focus will be on comparison of output voltage quality of two MTG interface converters (matrix converter and conventional rectifier-inverter structure). In order to perform a true comparison, switching frequency of both converters is set to 5 kHz and output LC filters parameters are chosen to be the same. The block diagram of the simulated system is shown in Fig above.

The reference speed of the MTG is set to 45000rpm. At first, The RLC load is 0.2pu. Then, at t=14sec, the load has a step increase to 0.8pu.

The torque response of the microturbine is compared with the load demand in Fig.7. It can be seen that the torque has a good convergence.

Also, speed of MTG is shown in Fig.8. As it can be observed, the speed converges to its reference value, too.

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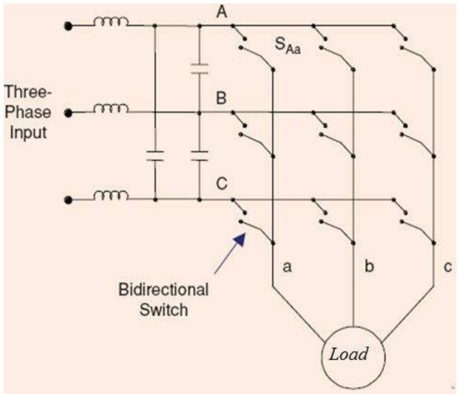


Fig 6 : Mechanical Torque of MTG

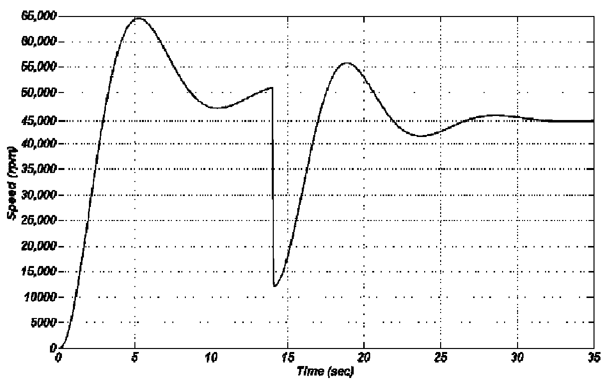
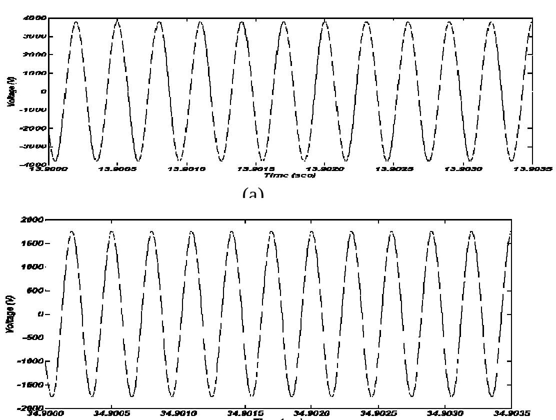


Fig.7 : Speed of MTG

At this speed, the output frequency of the PMSG is 3000Hz and must be converted to power system frequency(60Hz). As it is mentioned earlier, it can be achieved using matrix converter or conventional rectifier-inverter structure.

In Figs 9(a) and 9(b), PMSG output phase-a voltages at 0.2 pu and 0.8 pu loads are shown.



(a)

(b)

Fig. 8 : PMSG output voltage: (a)load=0.2 pu (b)load=0.8 pu

Matrix and conventional converters operate on these load voltages to construct a 60Hz, 440V(p-p) output voltage. Output waveforms of these converters before filtering are shown in Figs.10 and 11, respectively.

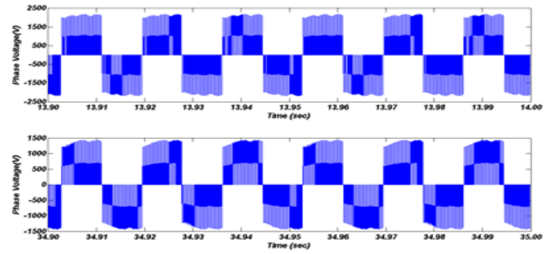


Fig 9 : MC output voltage: load=0.2pu (top) load=0.8pu (bottom)

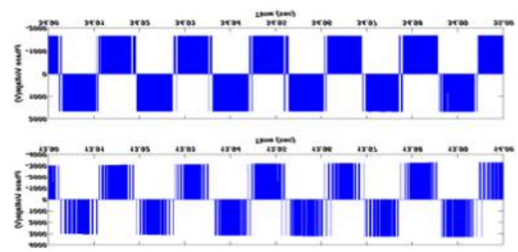


Fig.10 .Conventional converter output voltage: load=0.2 pu (top)load=0.8 pu (bottom)

These voltages are filtered by the LC filter to construct the load terminal voltages. Figs 12 and 13 show the filtered voltages waveforms. As it can be seen, the voltage THD values(5.5%and4.5%for0.2and0.8puloads) using MC are less than the ones in the case of conventional rectifier-inverter structure(7.2%and6.5%for0.2 and 0.8pu loads).

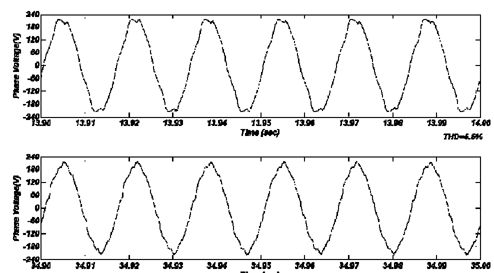


Fig. 11 : load terminal voltage using MC: load= 0.2 pu (top) load=0.8pu (bottom)

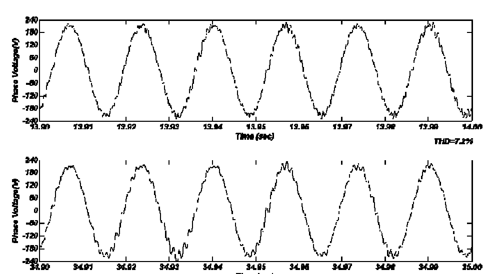


Fig.12 : load terminal voltage using conventional converter load=0.2pu (top) load=0.8pu(bottom)

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VII. CONCLUSIONS

In this paper, application of the matrix converter as output frequency converter in microturbine-generator is addressed. Comparison of simulation results of MTG using matrix and conventional interface converters demonstrated the ability of MC to deliver a higher-quality voltage to the load. Also, it is worthy to be noted that through application of MC the large dc link capacitor which is common in the rectifier-inverter structure is omitted. So, the interface converter can be more compact and less expensive.

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