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Micro-Turbine Generation Control System Optimization Using Evolutionary algorithm

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Abstract—
Distribution systems management is becoming an increasingly complicated issue due to the introduction of new technologies, new energy trading strategies, and new deregulated environment. In the new deregulated energy market and considering the incentives coming from the technical and economical fields, it is reasonable to consider Distributed Generation (DG) as a viable option to solve the lacking electric power supply problem. This paper presents a mathematical distribution system planning model considering three planning options to system expansion and to meet the load growth requirements with a reasonable price as well as the system power quality problems. DG is introduced as an attractive planning option in competition with voltage regulator devices and Interruptible load.

This paper presents a dynamic modelling and simulation of a high speed single shaft micro-turbine generation (MTG) system for grid connected operation and shows genetic algorithm (GA) role in improvement of control system operation. The model is developed with the consideration of the main parts including: compressor-turbine, permanent magnet (PM) generator, three phase bridge rectifier and inverter. The simulation results show the capability of Genetic Algorithm for controlling MTG system. The model is developed in Mat lab / Simulink.
Index Terms--Distributed Generation, Genetic Algorithm, Inverter, Micro-Turbine.

I. INTRODUCTION

Distributed Generation (DG) is expected to play a major role in the future of power generation systems. DG can help to reduce transmission losses, improve power quality to end users, and smooth peaks in demand patterns [1]. Although different works have been undertaken on modelling of micro turbine, it is essential to develop more models with higher precision. In [2]-[6] a dynamic model for combustion gas turbine has been discussed. In these references, the model was used to represent the gas turbine dynamics, including speed, temperature, acceleration and fuel controls. However, these works deal with heavy-duty gas turbine. A non-linear model of the micro-turbine implemented in NETOMAC software and a linear modelling of grid connected MTG system are reported in [7] and [8], respectively. The dynamic behaviour of the grid connected split shaft micro-turbine is done in [9]. A dynamic modelling of micro-turbine developed a generic model of the grid connected micro-turbine converter is reported in [10]. In [11] the evaluation of the electromagnetic transients of a grid connected MTG system that includes an AC-DC-AC converter is discussed.

The load following performance and modeling of split shaft micro turbine is developed in [12]. This paper presents a dynamic modeling of MTG system used genetic algorithm to determine the value of controller blocks coefficients in order to achieve the best control performance.

II.MICROTURBINE:

Micro turbines are small combustion turbines with outputs of 25 kW to 500 kW. They evolved from automotive and truck turbochargers, auxiliary power units (APUs) for airplanes, and small jet engines. Micro turbines are a relatively new distributed generation technology being used for stationary energy generation applications. They are a type of combustion turbine that produces both heat and electricity on a relatively small scale

A micro gas turbine engine consists of a radial inflow turbine, a centrifugal compressor and combustor. The micro turbine is one of the critical components in a micro gas turbine engine, since it is used for outputting power as well as for rotating the compressor. Micro turbines are becoming widespread for distributed power and combined heat and power applications. They are one of the most promising technologies for powering hybrid electric vehicles. They range from hand held units producing less than a kilowatt, to commercial sized systems that produce tens or hundreds of kilowatts. Part of their success is due to advances in electronics, which allows

unattended operation and interfacing with the commercial power grid. Electronic power switching technology eliminates the need for the generator to be synchronized with the power grid. This allows the generator to be integrated with the turbine shaft, and to double as the starter motor. They accept most commercial fuels, such as gasoline, natural gas, propane,
diesel, and kerosene as well as renewable fuels such as E85, biodiesel and biogas.

a)MICROTURBINEGENERATIONSYSTEM MODELING

There are essentially two types of micro turbine designs.One is a high-speed single-shaft design with the compressor and turbine mounted on the same shaft as the permanent magnet synchronous generator. The generator generates a very high frequency three phase signal ranging from 1500 to 4000Hz. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage. Another is a splitshaft design that uses a power turbine rotating at 3600 rpm and a conventional generator (usually induction generator) connected via a gearbox. The power inverters are not needed in this design.Along with the turbine there will be control systems including speed and acceleration control, fuel flow control,and temperature control. A micro turbine can generate power in the range of 25 KW to 500 KW. Fig. 1 shows the basic components of microturbine generation system [13].

b)MICROTURBINE MODEL

Its control systems which is implemented in Matlab / Simulink is shown in figure 2 [5, 6]. The model consists of speed governor, acceleration control blocks, fuel system control, and temperature control and turbine dynamics. The speed control operates on the speed error formed between a reference speed (1 p.u.) and the MTG system rotor speed. Speed control is usually modeled by using lead-lag transfer function or by a PID controller. Acceleration control is used primarily during turbine start up to limit the rate of the rotor acceleration prior to reaching the operating speed. The output of the governor goes to a low value select to produce a value for Vce, the fuel demand signal. The value of Vce is scaled by the gain value of 0.77. The time delay preceding the fuel flow controls represents delays in the governor control using digital logic in place of analog devices. The fuel flow, burned in the combustor results in turbine torque and in exhaust gas temperature measured by a thermocouple. The output from the thermocouple is compared with a reference value. The temperature control output will pass through the low value selector

III.SIMULINK MODEL OF THE MICROTURBINE:

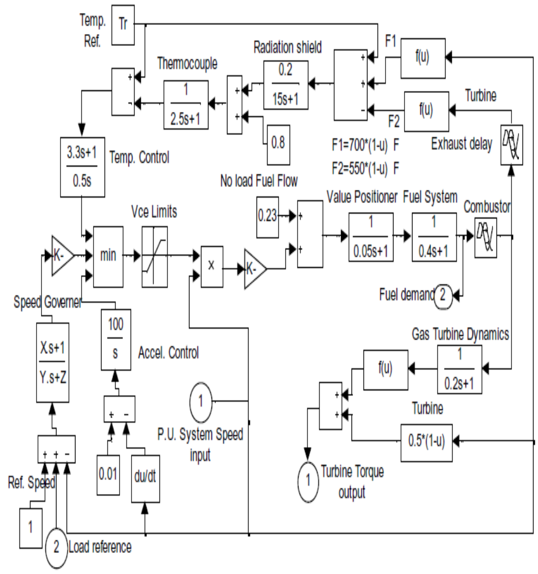


Fig.1 Simulink model of the microturbine:

IV) PERMANENT MAGNET SYNCHRONOUS MACHINE(PMSM)

The model adopted for the generator is a 2-pole Permanent magnet Synchronous Machine (PMSM) with a non salient rotor. The machine output power is 30 kW and its terminal line to line voltage is 480V. The electrical and mechanical parts of the machine are each represented by a second order state space model. The model assumes that the flux established by the permanent magnets in the stator is sinusoidal, which implies that electromotive forces are sinusoidal. The following equations expressed in the rotor reference frame (dq frame) used to implement PMSM [7, 8].

J :Combined inertia of rotor and load
L_q, L_d :q and d axis inductances
p :Number of pole pairs
R :Resistance of the stator windings
T_e :Electromagnetic torque
T_M :Shaft mechanical torque
v_q, v_d :*q and d axis voltages*
θ :Rotor angular position
λ :Flux induced by the permanent magnets in the stator windings
ω_r :Angular velocity of the rotor

V. LCL FILTER

The primary function of the AC filter is to filter out the high frequency components caused by the inverter switching operation. However, the filter also affects the low order harmonic performance of the system. The passive LCL filter design depends on the attenuation needed in order to reduce the high frequency component of the line current. The LCLfilter aims to reduce the high order harmonics at grid side (load side), but a poor design of the filter can cause a lower attenuation compared to that expected or even an increase of the distortion due to oscillation effects. In fact the current harmonics generated by the rectifier or inverter can cause saturation of the inductors or filter resonance. So, the inductors should be correctly designed considering the current ripple and the filter should be damped to avoid resonance. The transfer function of the LCL filter designed by the output voltage to the input current .

$$G^{\alpha\beta}(s) = \frac{\dfrac{1}{L_1 + L_2 C}}{s\left(s^2 + \dfrac{L_1 + L_2}{L_1 L_2 C}\right)}$$

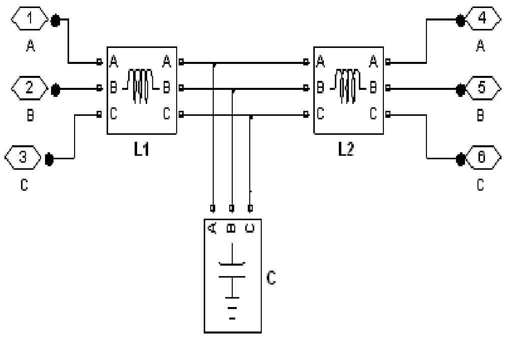


Fig .2 LCL Filter

The design of LCL filter is shown in figure 3. The three-phase active LCL filter,capacitive load injected the reactive power into the system as well as do harmonics attenuation. The values for LCL filter configuration with inverter side inductance (L1) and line side (L2) are 6.5mH and 1mH and capacitive load value considered is 3.5kVar.

VI) INVERTER

The inverter is used to convert DC voltage to ac in an appropriate frequency, as mentioned before. When running in parallel with the power grid, the grid itself fixes the frequency. Fixed power control is used to control the transmission. On a stand – alone system, the frequency will be defined by the load. a voltage control could be applied to the inverter, and the inverter real and reactive power will be defined automatically [14]. So depending on the status of the power plant, there are two different control strategies for the inverter:

PQ control strategy, when MTG system is in grid connected operation and V-f control strategy, for operating in stand-alone mode;

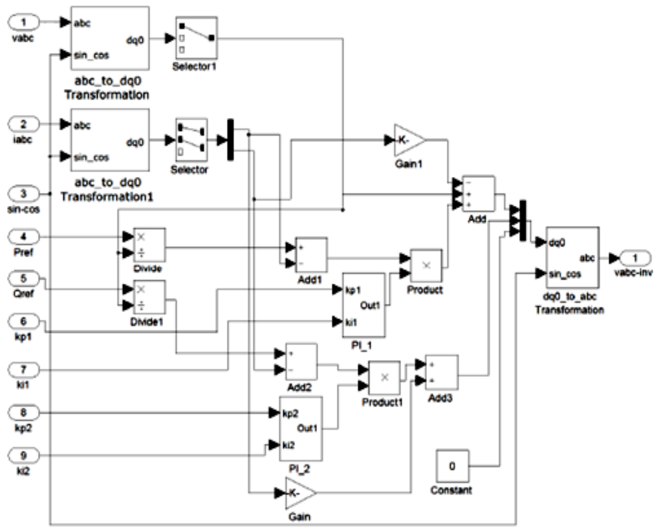


Fig .4 Inverter control scheme in grid connected mode

In this paper the grid connected system is considered and the genetic algorithm is used to improve the control loop operation. The inverter controls the active and reactive power injected to the grid, which have to follow the set-points Pref and Qref . These set-points can be chosen by customer or by a remote control [13]. The initial value of Pref is 9kW, Qref is 3Kvar, then Pref steps up to 18kWand Qref steps up to 5.5Kvar in 0.5 s. The inverter is current controlled, and two PI controllers are used to regulate the grid current components, i.e. id and iq. Fig. 2 shows the Simulink model of first PI controller and the inverter control system model is shown in Fig. 3. In section V, the values of the coefficients related to each of these two PI controllers are determined, i.e. kp1 and ki1 for first PI controller and kp2 and ki2 for second one.

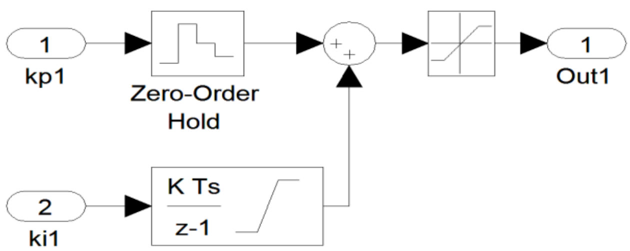


Fig.3 PI Controller Scheme

VII) GENETIC ALGORITHM

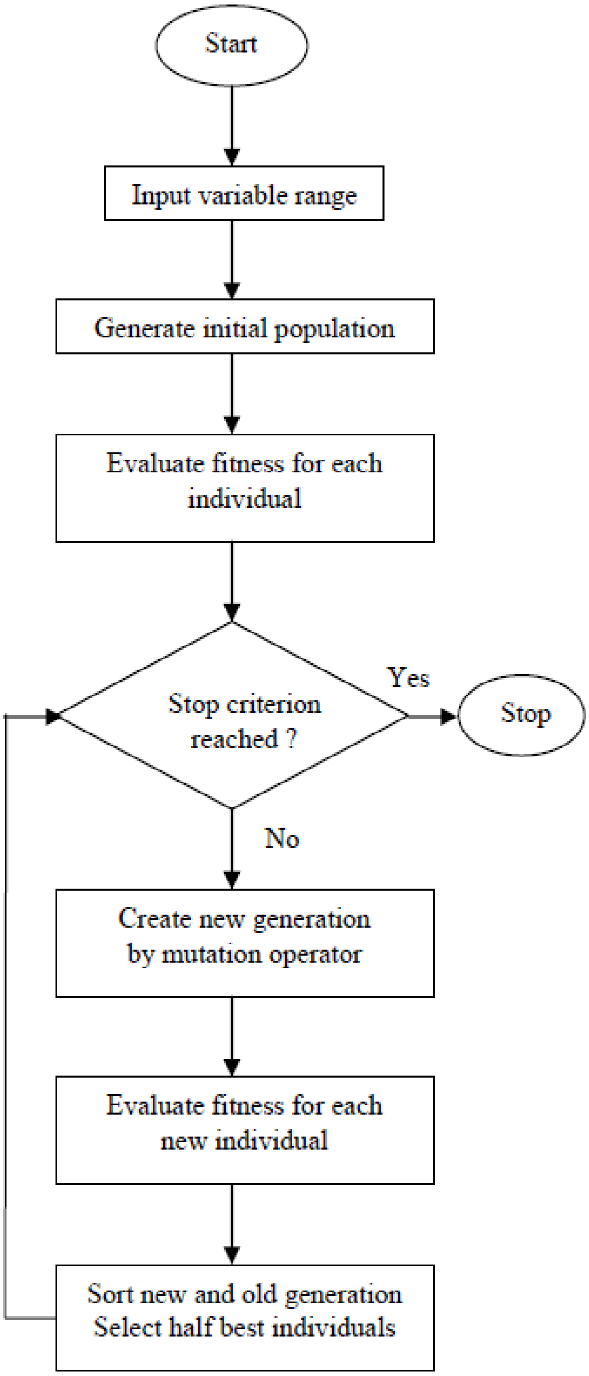
Genetic algorithms are probabilistic search approaches which are founded on the ideas of evolutionary processes. The GA procedure is based on the Darwinian principle of survival of the fittest. An initial population is created containing a predefined number

of individuals or solutions, each represented by a genetic string incorporating the variable information. Each individual has an associated fitness measure, typically representing an objective value. The concept that fittest individuals in a population will produce fitter offspring is then implemented in order to reproduce the next population. Selected individuals are chosen for reproduction or crossover at each generation, with an appropriate mutation factor to randomly modify the genes of an individual, in order to develop the new population. The result is another set of individuals based on the original subjects leading to subsequent populations with better individual fitness. Therefore, the algorithm identifies the individuals with the optimizing fitness values, and those with lower fitness will naturally get discarded from the population[15].

Genetic Algorithms are a class of problems of producing best solutions while solving complex optimisation problems. They are capable of the search space. According to the Holland, this class of evolutionary algorithms is different from the other classes in three features.

- Representation
- Selection
- Cross over

Flow Chart For Genetic Algorithm



In this work we use genetic algorithm to determine the values of PI controllers coefficients until the active and reactive power injected to the grid follow Pref and Qref in the best manner. The fitness function is the difference between the active power injected and Pref.The best fitness amount was calculated 6.5179, although the amount is not constant and the nature of genetic algorithm causes it changes in another running. The results obtained by GA to minimize the fitness function are shown in Table .

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parameters	Value/Type
Population size	20
Type of selection	Stochastic uniform
Type of cross over	Scattered(Probability=0.8)
Type of mutation	Use constraint dependent default

Output Using GA

Proposed PI Controllers Parameters

parameters	Kp1	Ki1	Kp2	Ki2
values	0.9592	0.8782	0.8659	0.8955

VIII) SIMULATION RESULTS AND DISCUSSION

To clarify the control strategy in grid connected operation, a test system is used, as shown in appendix. The test system has a nominal speed of 66000 rpm / min and a rated capacity of 55kW. A load of 50 kW with the frequency of 50 Hz is applied on the MTG system

Fig.4 shows the active power and the reactive power outputs when GA is used. Fig.4 shows the active power and the reactive power outputs when GA is not used.where , the active power output reaches Pref after0.0171 s when Pref steps up to 18kW , but it takes more than 0.05s. The voltage across the stator terminals of generator is shown in Fig. The variation of the current in phase a according to the variation of set-points (Pref and Qref)

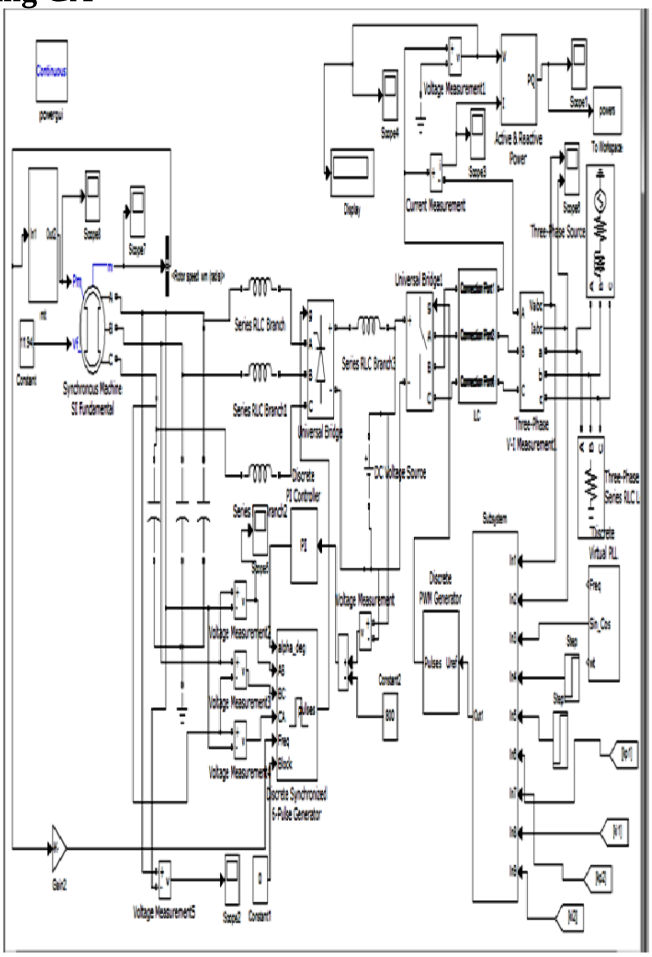

Fig.4 Waveforms

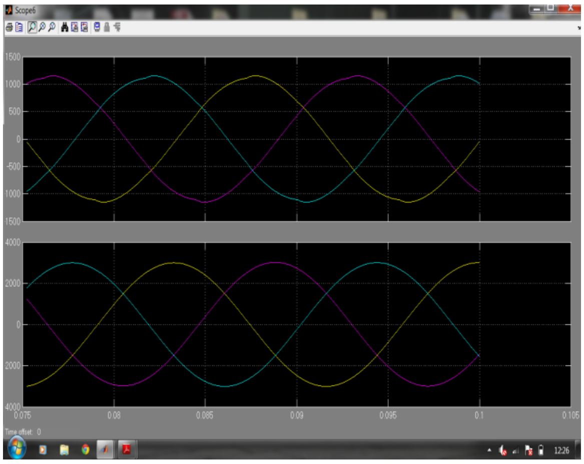

Fig.5 Three phase voltage

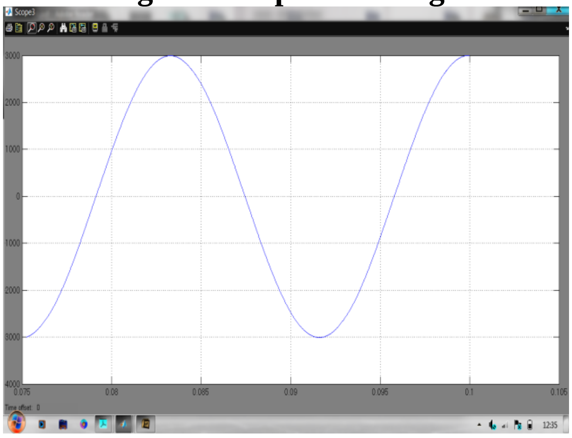

Fig.6 current of phase a

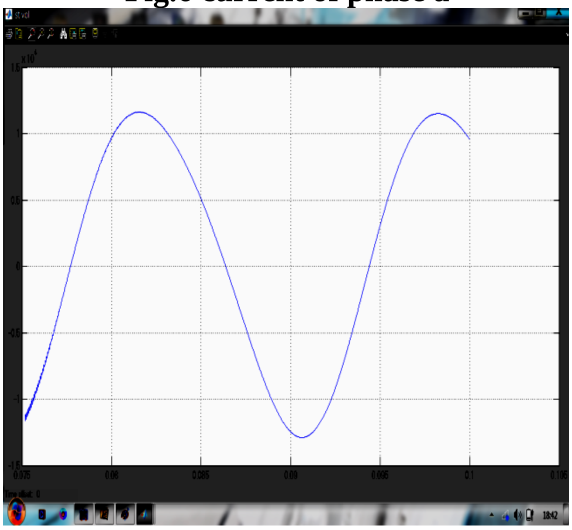

Fig .7 stator voltage

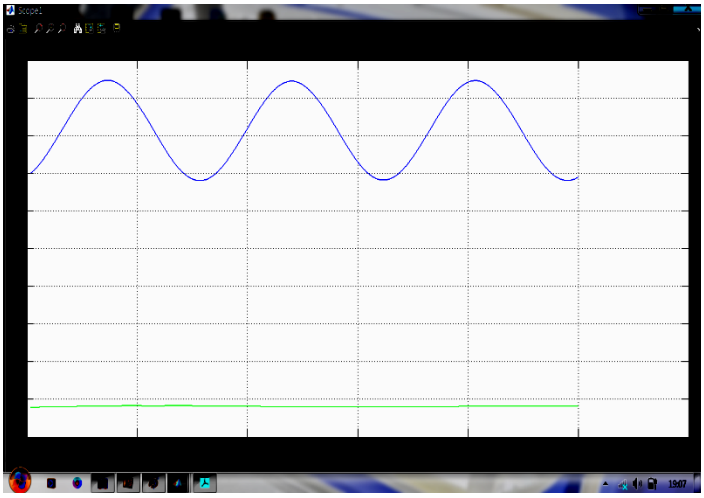

Fig. 8 Real and Reactive power with GA

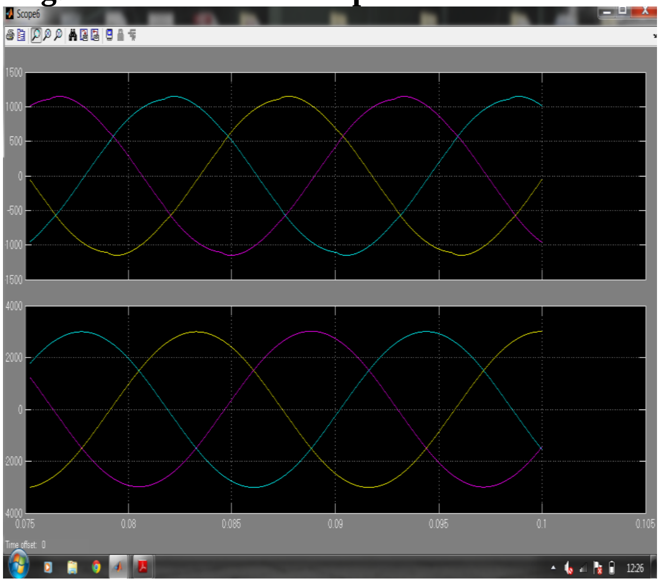

Fig.9 inverter output

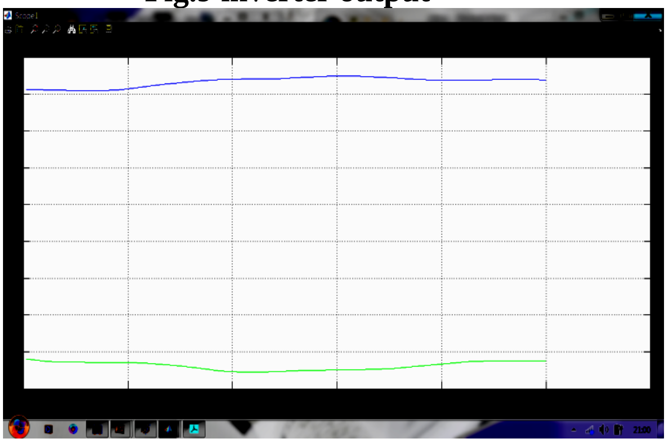

Fig.10 Active and Reactive power

XI .CONCLUSION

A modelling of a single-shaft micro-turbine generation system suitable for connected DG application is developed in this paper. GA application in modelling of the control system of the microturbine is also given. GA is applied in order to improve the control system performance by determining the values of the PI controller's coefficients. The results show that the developed model provides a useful tool suitable to study the various performances of micro-turbines in grid connected operation. They also show that the use of GA can improve the control system operation.

Micro turbines are relatively new in the market and are attracting wide attention due to their varied applications. Development of a sophisticated engineering product like micro turbine is a continuous process. A lot of work is yet to be done on the design aspects before the micro turbine can be readied for market consumption. The design procedure has to take into various other parameters to make it suitable for practical applications. Also, manufacturing of such complex shapes of minute size is another ongoing research work. Further research into the design and manufacture process would result in production of even better micro turbines.

REFERENCES

[1] Ghasemi,N., Abedi,M., Rastegar,H, and Gharepetian,G., "Hybrid distributed generation units PEM fuel cell and microturbine," *Industrial Technology,2008.ICIT 2008, IEEE International Conference on,* pp.1-6, 21-24 Aprill 2008.

[2] W. I. Rowen, "Simplified mathematical representations of heavy duty gas turbines," *Journal of Engineering for Power, Trans. ASME,* vol. 105, no. 4,pp. 865-869, October 1983.

[3] L.N. Hannet and Afzal Khan, "Combustion turbine dynamic model validation from tests," *IEEE Trans. on Power Systems,* vol.8, no.1, pp. 152-158, February 1993.

[4] Working Group on Prime Mover and Energy Supply Models for System Dynamic Performance Studies, "dynamic models for combined cycle plants in power system studies," *IEEE Trans. Power System,* vol. 9, no.3, pp. 1698-1708, August 1994.

[5] L.N. Hannett, G. Jee, and B. Fardanesh, "A governor/turbine model for a twin-shaft combustion turbine," IEEE *Trans. on Power System,* vol.10, no. 1, pp. 133-140, February 1995.

[6] L. M. Hajagos and G. R. Berube, "utility experience with gas turbine testing and modeling," *in Proceedings, IEEE PES Winter Meeting,* vol. 2, pp. 671-677 January /February 2001, Columbus, OH.

[7] H. Nikkhajoei and M.R. Iravani, "Modeling and analysis of a microturbine generation system," *IEEE Power Engineering Society Summer Meeting*, vol .1, pp. 167 -169, 2002.

[8] R. Lasseter, "Dynamic models for micro-turbines and fuel cells," *in Proc. IEEE PES Summer Meeting,* vol. 2, Vancouver, Canada,2001, pp.761-766

[9] A. Al-Hinai, K. Schoder, and A. Feliachi, "Control of grid-connected split shaft microturbine distributed generator," *System Theory,Proceedings of the 35th Southeastern Symposium*, pp. 84 –88, *2003.*

[10] Lasseter Robert, "Dynamic models for micro-turbines and fuel cells," *Proceedings ,IEEE PES Summer Meeting,* vol. 2, pp. 761-766, July 2001, Vancouver, Canada.

[11] H. Nikkhajoei and R. Iravani, "Electromagnetic transients of a microturbine based distributed generation system," *in Proc. International Conference on Power Systems Transients (IPST'05),* Montreal, Canada,2001.

[12] Y. Zhu and K. Tomsovic, "Development of models for analyzing the load-following performance of microturbines and fuel cells," *Journal of Electric Power Systems Research,* vol. 62, pp. 1-11, 2002.

[13] Zhou Yunhai and Stenzel ,J, "Simulation of a microturbine generation system for grid connected and islanding operation," *Power and Energy Engineering Conferences ,2009. APPEEC 2009.* Asia-Pacific ,27 – 31 march 2009, pp. 1 – 5.

[14] Tao Yu and Jia-Peng tong, "Auto disturbance rejection control of microturbine system," *Power and Energy Society Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE,* pp. 1 – 6, July.2008.

[15] Kahouli,A., Guesmi,T., Hadj Abdallah and Ouali,A., "A genetic algorithm PSS and AVR controller for electrical power system stability,*" System, Signal and Devices, 2009. SSD'09. 6th International Multi-Conference on,* pp. 1-6,23- 26 March 2009.

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