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Dynamic Performances of Split-Shaft Microturbine Generator (MTG) and Diesel Generator as Distributed Energy Resources

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Abstract : This paper presents the dynamic analysis of load following performances of split-shaft microturbine generator (MTG) and Diesel Generator systems considering P-I type load following and P-I type speed controllers under stand-alone mode of operation. In this paper microturbine system coupled with a synchronous generator (SG) is considered. The dynamic performances of split-shaft MTG and Diesel Generator system are also examined when they are connected together to satisfy the load demand. Finally, the MTG and diesel generator systems are connected to an 11 kV rural distribution network to examine the transient behaviour during active power injection. Simulation result for all the cases are analyzed and presented in this paper.

Keywords: Distributed Generation (DG), Split-Shaft Microturbine Generator(MTG), Diesel Generator, Speed Controller, Load Following Controller, Distribution Network

1.INTRODUCTION

With recent technological development and to cope with rapidly increasing load demand, distributed generations (DGs) become an inseparable part of power generation and distribution system. Supplying electric power to the final user through generation, transmission, and distribution system causes high amount of power loss. By adopting distributed generation system this losses can be reduced and also it will be possible to supply electric power to the rural areas where utility grid can't supply electric power. DGs have various benefits to the customer, utilities, and to the environment. DG can be defined as "small and medium size modular electric generation system near to the load"[1]. The examples of DG sources are Solar cell, Wind turbine, Microturbine, Diesel Generator, Fuel cell etc. DG sources can operate in stand-alone mode as well as when connected to the utility grid. To integrate DGs in the existing electric network several technical regulatory and industrial aspect need to be followed [1]. Microturbine and diesel generator are very common example of DG. Microturbine generator (MTG) are useful for peak load saving customer's base-load requirements. It can also be used for stand by and cogeneration application. Diesel Generator is well known generating system for back up supply and to supply electric power to the rural areas.

Microturbine is a part of general evaluation of gas turbine technology with improved performance and efficiency. Microturbines are small and simple cycle gas turbine with output ranging from 25 kW to 500 kW. Low emission technology which is incorporated in MTG system makes MTG system as an environment friendly generation system. MTG can run on different fuels like natural gases methane, ethanol, other land fill gases, and diesel. There are two type of MTG system. One is high speed single shaft unit with the compressor and turbine are mounted on the same shaft as the electric alternator; the turbine speed of single-shaft MTG system is mainly ranges from 50000 rpm to 120000 rpm. Due to this high speed of the turbine the alternator generates electric power at high frequency (1500 Hz – 4000 Hz), which is converted to the rated frequency by using a power electronics interference. The other type of MTG system is split-shaft MTG system in which the shaft of the turbine is connected to the shaft of the generator via a gear box. Gear box is used in the system to multiply the speed. Split-shaft design of MTG system uses power turbine which rotates at 3000 rpm / 3600 rpm and generates power at rated frequency. So electronics interference is not required. Synchronous generator or induction generator can be used in the design of MTG system. Details development of Microtrubine technology is discussed in [2,3,4].

Diesel Generator is a combination of diesel engine which runs on diesel and an electrical alternator which converts the mechanical power generated by diesel engine into electrical power. Diesel Generator is a very reliable source of electrical power. It is used in house as well as in industries. The output power range of Diesel Generator is from few kW to few MW.

The dynamic modeling of MTG system has been studied by several researchers. Load following performance of MTG system is studied by Zhu and Tomsovic [5], which shows that the MTG system is capable of providing load – following services. El-sharkh et al [6] have studied the load following performance of MTG system with fuel cells. El-Sharkh uses speed controller to keep the speed deviation of the system to its nominal value. Jurado and Saenz [7] have proposed an adaptive control technique to control the system for hybrid power system application with fuel cells. Bertani et al [8] have studied the dynamic performances of MTG system in stand-alone and grid connected mode of operation. Ho et al [9] have studied the

MTG system's performance when it is used for cogeneration purpose. Saha et al [10] have studied the load following performances of MTG system under different loading condition. Malatestas et al [11] have presented the dynamic model of Diesel Generator, he also have studied the dynamic model of Diesel Generator when it is used as a part of hybrid power generation system with wind turbine. Stavros et al [12] also have studied the dynamic performance of wind-diesel generation system in autonomous mode. Abdin et al [13] design a controller for a stand-alone photovoltaic – diesel generator unit using proportional – integral (PI) controller to control the generation of power.

Most of the researchers of MTG system have considered single – shaft design of MTG system. Single – shaft MTG system uses permanent magnet synchronous generator (PMSG) or asynchronous generator. Single – shaft design of microturbine coupled with PMSG or asynchronous generator is simple and it require power electronics rectifier – inverter to supply the load at nominal voltage and frequency [5,8,14]. Asynchronous generators are cost effective and robust, but their speed depends on load and it also requires power electronics interference for grid connection. On the other hand use of high speed PMSG for single – shaft MTG system have some drawbacks, such as high centrifugal force, more thermal stress, rotor losses due to fringing effects, demagnetization effect, high cost etc [8,14]. Use of power electronics interference for single – shaft MTG system to convert the frequency of the generated power to the nominal frequency also causes harmonics in generated voltage. Very few researchers have considered split – shaft design of MTG system coupled with synchronous generator (SG), and studied the dynamic performance of MTG system but complete block diagram representation with proper controller is not available in the literature [10,15]. Main advantage of split – shaft MTG system is that it does not require electronics interference to convert the frequency of the generated AC power. Use of SG for split – shaft MTG system eliminates the need of power electronics interference for grid connection. In split – shaft MTG system the turbine is connected to the generator via a gear box to generates power at nominal frequency (50 Hz / 60 Hz). Diesel Generator mainly uses synchronous generator [11,12] or PMSG [16]. Diesel Generator can be used for hybrid power system with other power generation system like wind – turbine, fuel – cells, photovoltaic system [12,16,17,18].

In this paper split – shaft MTG system coupled with SG is considered. The load following performance of split – shaft MTG system and Diesel Generator has been studied in stand – alone mode of operation and also when MTG system and Diesel Generator are connected together for supplying the load demand has been studied. The main interest of this paper is to control the active power generation with minimal frequency deviation, for that PI controller is used. For MTG system a proportional integral (PI) type of load following controller is used to control active power generation of MTG system and another PI type of speed controller is used to control frequency deviation of the system. For Diesel Generator one PI type of load following controller which control the active power generation and one PI type of speed controller which control the frequency deviation are used. The dynamic performance of MTG and Diesel Generator in stand–alone mode has been studied and presented in this paper. This research work is also carried out to study the performance of split – shaft MTG and Diesel Generator systems when they are connected to a rural distribution. To the best of the authors' knowledge, this important issue was also not addressed by the previous researchers.

2. ASSUMPTIONS AND LIMITATIONS

(a) Fast dynamics such as loss of power, fault, and startup and shutdown transient are not considered.

(b) Main interest of this paper is on the electro-mechanical behavior of the microturbine and Diesel Generator at normal operating condition, where load can change suddenly or gradually.

(c) Under normal system conditions, acceleration control and temperature control are of no significance and has not been considered in the mathematical model.

3. DYNAMIC MODELING OF SPLIT-SHAFT MICROTURBINE SYSTEM

Zhu and Tomsovic [5] have presented details model of split-shaft MTG system. They have used GAST model of gas turbine without droop to describe the details modeling of split-shaft MTG system. This GAST model is a Western System Coordinating Council (WSCC) compliant model and the model is simple and follows all the guideline of modeling [19]. In this paper authors have used widely accepted GAST turbine model. The model is shown in **Fig.1**, along with control system and power system block. The main blocks are –

A. Burner:- Burner mainly consists of compressor and combustion chamber, where first the air is being pressurized, after that fuel mixed with the pressurized gas and burned in the chamber. Burner block can be represented by a first order transfer function with time constant of T_1.

B. Turbine:- Output of burner means the hot and pressurized gas is the input to the turbine block, which drives the turbine and generates power (P_m). Split-shaft turbine is represented by a first order transfer function block having time lag constant T_2.

C. Temperature control loop:- Temperature control loop plays an important role in MTG system modeling. It controls temperature of the system by controlling generated output power by MTG system. Temperature control loop has a lag time constant of T_3.

D. Control system:- For the purpose of controlling the system and to get optimal result, control system plays a vital role. To control the generation of the MTG system one PI type load following controller is used having proportional and integral gain of K_p' and K_i' respectively. Another PI type of speed controller having proportional and integral gain of K_p" and K_i" respectively. The purpose of the speed controller is to supply electric power to the load with minimal frequency deviation.

E. Power system:- The microturbine output being the mechanical power change ΔP_m. If ΔP_{Le} represents an electrical load change, the difference $(\Delta P_m - \Delta P_{Le})$ is absorbed by the power system, where the MTG system is connected. Now $(\Delta P_m - \Delta P_{Le})$ is accounted for in two ways [20, 21]:

I. Rate of increase of stored kinetic energy (KE) in the generator rotor.

At scheduled system frequency (f_0), the stored energy is

$$W_{ke}^{0} = H \times P_{rated} \text{ kW-Sec} \qquad (1)$$

Where

P_{rated} = rated capacity of MTG (kW)
H = inertia constant (Sec).

The kinetic energy is proportional to square of the speed (hence frequency). The kinetic energy at frequency ($f_0 + \Delta f$) is given by

$$W_{ke} = W_{ke}^{0}\left(\frac{(f_0+\Delta f)}{f_0}\right)^2$$

$$\therefore\ W_{ke} \approx HP_{rated}\,(1 + \frac{2\Delta f}{f_0})$$

$$\therefore\ \frac{d}{dt}(W_{ke}) = \frac{2HP_{rated}}{f_0}\frac{d}{dt}(\Delta f) \qquad (2)$$

II. It is assumed that the load is sensitive to the speed (frequency) variation. However, for small change in system frequency Δf, the rate of change of load with respect to frequency, that is $\frac{\partial P_{Le}}{\partial f}$ can be regarded as constant. This load changes can be expressed as:

$$\left(\frac{\partial P_{Le}}{\partial f}\right).\Delta f = D^{'}.\Delta f \qquad (3)$$

Where $D^{'} = \frac{\partial P_{Le}}{\partial f}$ = constant.

Therefore, the power balance equation can be written as:

$$\Delta P_m - \Delta P_{Le} = \frac{2HP_{rated}}{f_0}\frac{d}{dt}(\Delta f) + D^{'}\Delta f.$$

$$\frac{\Delta P_m}{P_{rated}} - \frac{\Delta P_{Le}}{P_{rated}} = \frac{2H}{f_0}\frac{d}{dt}(\Delta f) + \frac{D^{'}}{P_r}\Delta f\ .$$

$$\therefore\ \Delta P_m(pu) - \Delta P_{Le}(pu) = \frac{2H}{f_0}\frac{d}{dt}(\Delta f) + D\Delta f\ . \qquad (4)$$

Where $D = \frac{D^{'}}{P_{rated}}$ (5)

In Eqn. (4), ΔP_m and ΔP_{Le} are now in per unit (pu) values. Taking the Laplace transform of Eqn. (4), we get:

$$\Delta f(s) = \frac{\Delta P_m(s) - \Delta P_{Le}(s)}{\left(D + \frac{2H}{f_0}s\right)}$$

$$\therefore\ \Delta f(s) = [\Delta P_m(s) - \Delta P_{Le}(s)] \times \frac{K_p}{1+sT_p} \qquad (6)$$

Where,

$T_p = \frac{2H}{Df_0}$ = power system time constant.
$K_p = \frac{1}{D}$ = gain of power system.

The parameters of the system model are given in **Appendix**. Microturbine does not have governor, so governor model is omitted. As the effect of damping of turbine on dynamic performance is negligible [5], damping of the turbine is neglected. Another important part of MTG system is recuperator, which is a heat exchanger to rise the efficiency of the MTG system. Due to very slow response time of recuperator, it has little influence on the time scale of our dynamic simulations, so recuperator is not considered in this model. It is also assumed that split-shaft MTG system has 120% peak power capacity. So $L_{max} = V_{max} = 1.2$. Combing all the blocks as described above the block diagram representation of the MTG system is shown in **Fig. 1.** The value of gains of the load following controller and speed controller of MTG system are selected using trial and error method and taken as constant for this study.

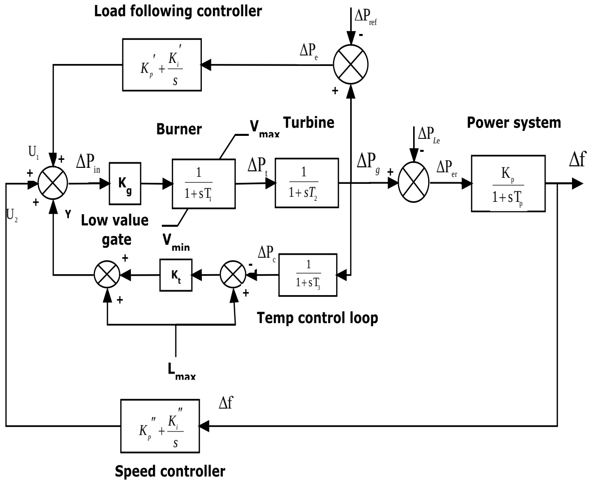

Fig. 1: Block diagram representation of Split-shaft microturbine with P-I type speed controller and P-I type load following controller

4. DYNAMIC MODELING OF DIESEL GENERATOR

Model of Diesel Generator in [11, 12] describe the dynamic behavior of small size Diesel Generator set. This model is widely accepted as the standard model of Diesel Generator. As mentioned Diesel Generator is a combination of diesel engine and an electric alternator. Diesel engine mainly consists of speed governor, a valve actuator servomechanism and diesel engine. Valve actuator and diesel engine can be represented by first order transfer function with time lag constant of T_{sm} and T_D respectively. As the variation of valve actuator value is very slow and can be negligible for small time intervals [22], the valve actuator is represented by constant parameters. Governor works as feedback loop to keep system speed / frequency to the nominal value. **Fig. 2** shows the block diagram representation of Diesel Generator with two P-I type of controllers.

One controller is load following controller having proportional and integral gain of $K_{Dp}^{'}$, and $K_{Di}^{'}$ respectively to control the generation of the Diesel Generator, and the other P-I type of controller is speed controller with proportional and integral gain of $K_{Dp}^{''}$, and $K_{Di}^{''}$ respectively to supply the power at nominal frequency.

To convert generated mechanical power by diesel engine, to electric power a synchronous generator is used. As like MTG system, power system block also can be modeled for Diesel Generator. The power system block is also shown in **Fig.2.** The parameters of the Diesel Generator system as shown in **Fig.2** are given in **Appendix**.

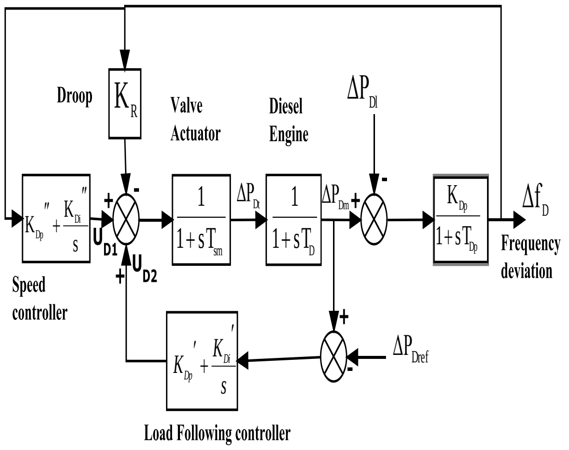

Fig. 2: Block Diagram representation of Diesel Generator with P-I type speed controller and P-I type load following controller

5. DYNAMIC ANALYSIS OF SPLIT-SHAFT MTG AND DIESEL GENERATOR SYSTEMS IN STAND-ALONE MODE

Dynamic performances of split-shaft MTG system shown in **Fig.1**, and Diesel Generator shown in **Fig.2** are analyzed in this section for stand-alone mode of operation. For this study, it is assumed that the MTG and Diesel Generator systems were running on no-load condition for 10 sec. After that a load disturbance of 0.5 pu is applied to both MTG and Diesel Generator system.

Fig.3 and **Fig.4** show the frequency deviation response and active power generation response for both MTG and Diesel Generated system respectively. From **Fig.3** , it can be seen that when sudden load disturbance is applied to both MTG and Diesel Generator system sudden frequency drop occurred, and it takes some time to reach steady state condition at which frequency deviation is zero. At steady state the active power generation of both MTG and Diesel Generator system is same with the load demand (0.5 pu) which can be seen in **Fig. 4**. Comparing the dynamic performances of MTG and Diesel generator systems, it is seen from **Fig.3** and **Fig.4** that the peak deviation and settling time is more for MTG system as compared to that obtained with Diesel generator system. From this study it can be concluded that both split-shaft MTG and Diesel Generator systems are capable for load following performances.

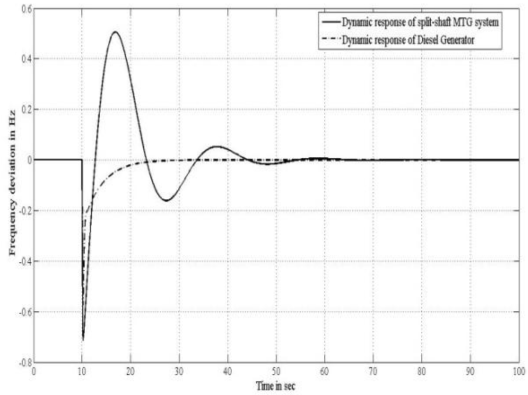

Fig. 3: Dynamic response of frequency deviation of split-shaft MTG and Diesel Generator systems in Hz

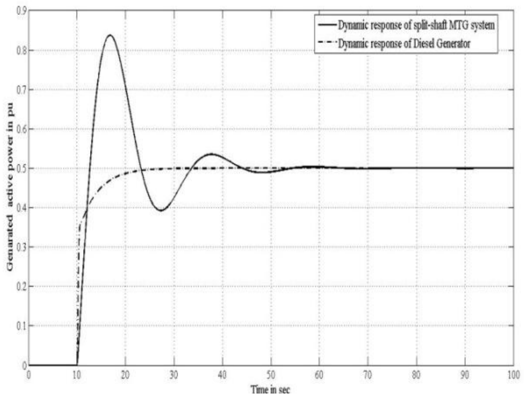

Fig.4: Dynamic response of generated active power by split-shaft MTG and Diesel Generator systems in pu

6. COMBINED OPERATIONS OF SPLIT-SHAFT MTG AND DIESEL GENERATOR SYSTEMS.

The block diagram representation of the combined model is shown in **Fig. 5**. The total load will be shared between the generating units. For this study it is assumed that the load sharing is same for both the generating unit, means both MTG system and Diesel Generator system will share 50% of the total load demand.

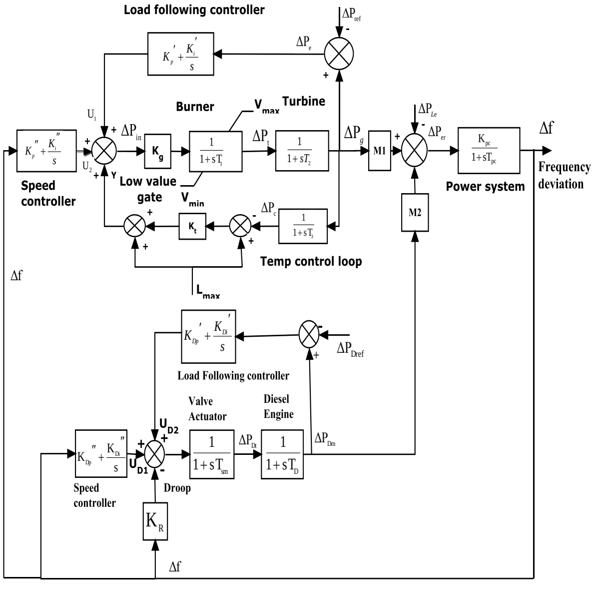

Fig. 5: Block diagram representation of the system when split-shaft MTG system and Diesel Generator are connected together

To study the dynamic performance of combine set of MTG and Diesel Generator system, it is assumed that the combine system was running on no-load condition for 10 sec, after that a load disturbance of 0.5 pu is applied to the system. **Figs. 6 & 7** show the frequency deviation responses of the combine system and active power generation by each of the generating unit respectively. From **Fig. 6** ,it can be noticed that when sudden load is applied there is a deviation in frequency but at steady state the frequency deviation becomes zero. At steady state the active power generation by each of the generating unit is generating 0.25 pu of power which can be seen in **Fig.7**.

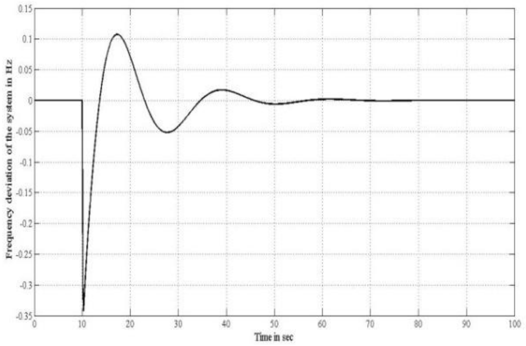

Fig. 6: Dynamic response of frequency deviation of combine split-shaft MTG and Diesel Generator system in Hz

From the dynamic analysis of split-shaft MTG system and Diesel Generator system connected together it can be concluded that both the generating unit (MTG and Diesel generator system) works very well and supply require power to the load.

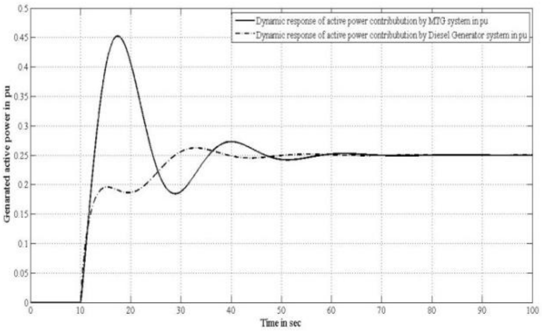

Fig.7: Dynamic response of active power generation by individual generating unit contributing to the load of combine split-shaft MTG and Diesel Generator system in pu

7. ACTIVE POWER PENETRATION IN A RURAL RADIAL DISTRIBUTION NETWORK BY SPLIT-SHAFT MTG AND DIESEL GENERATOR SYSTEMS.

To study the effect of active power penetration in a rural radial distribution network by split-shaft MTG and Diesel Generator system, a 12 node 11 kV rural distribution network shown in **Fig. 8** is considered. Data of this distribution network is given in **Appendix**. Now a MTG system and a Diesel Generator system are connected at node 5 and node 9 respectively through 440 V/ 11 kV (Δ - Y) transformer and circuit breaker S1 and S2 respectively. For MTG system the reference active power generation (P_{ref}) is set at 0.6 pu (150 kW), and for Diesel Generator system the reference active power generation (P_{Dref}) is set at 0.4 pu (100 kW). So when both the DG systems are in operation, it will inject a total of 250 kW of active power to the distribution network.

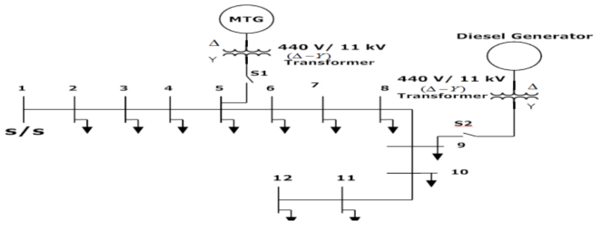

Fig.8: Single line diagram of 11 kV rural distribution network with MTG and Diesel Generator connected to it

To analyze the responses clearly it is considered that the generating units will start operating at different time. For the first 10 sec both the MTG and Diesel Generator units were running on no-load condition and at that time the active power injection by the DGs was zero. Then at 10 sec MTG got connected to the distribution network by closing the Circuit breaker S1 with the set reference active power generation ($P_{ref} = 0.6$ pu). After some time, at time t = 70 sec , Diesel Generator system got connected to the distribution network by closing circuit breaker S2 with the set reference active power generation ($P_{Dref} = 0.4$ pu).

Figs. 9,10,11,12 and **13** show the dynamic responses during transient imbalance. Initially system was on no load condition for 10 sec. **Fig. 9** shows the dynamic responses of active power generation by MTG and Diesel Generator systems. It can be seen from **Fig.9** that MTG system starts operating at 10 sec and Diesel Generator starts operating at 70 sec, and at steady state both MTG and Diesel Generator system generates the same active power equal to the load reference set point (0.6 pu for MTG system and 0.4 pu for Diesel Generator).

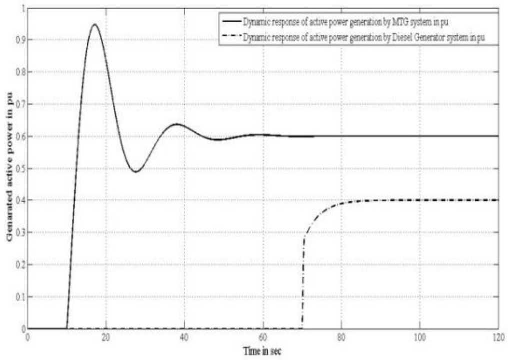

Fig.9: Dynamic responses of active power generated by split-shaft MTG and Diesel Generator systems connected to a 12 node rural distribution network

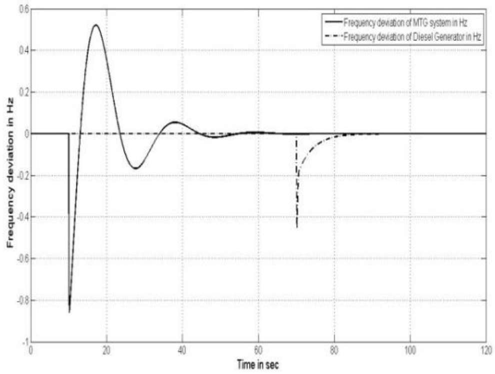

Fig.10: Frequency deviations of DGs connected to the rural distribution network.

Fig.10 shows the frequency deviations of both the DGs and it is seen that at steady state these deviations are zero. **Fig.11** shows the dynamic response of the voltage profile of node 8 of the distribution network. From **Fig.11** , it can be seen that with the penetration of active power by MTG and Diesel Generator, the voltage profile of the node 8 improves significantly. Similar findings for voltage improvement were also observed for other nodes also.

Fig.12 shows the variation of active power loss during active power penetration to the distribution network. From **Fig.12**, it is seen that active power loss has decreased from 20.71 kW to 14.63 kW

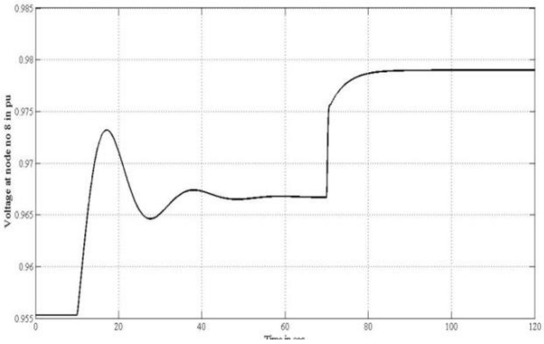

Fig.11: Dynamic response of voltage magnitude at node 8 of the rural distribution network

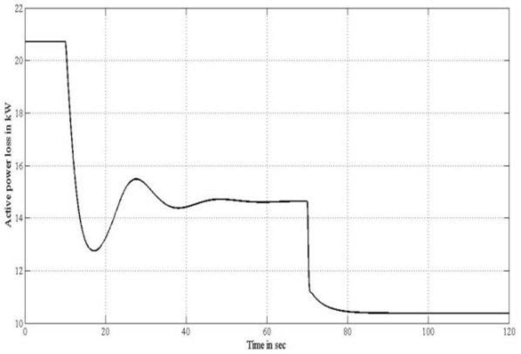

Fig.12: Variation of active power loss of the rural distribution network due to active power penetration by MTG and Diesel Generator systems in kW.

The steady state voltage magnitude of the network before and after connecting MTG and Diesel Generator system is given in **Table–1**. Significant improvement of voltage profile of the distribution network at steady state can be noticed when MTG and Diesel Generator are connected to the rural radial distribution network.

TABLE-1: Voltage magnitudes of 12 nodes of distribution network

Node no	Voltage magnitudes without DGs connected to the distribution network (pu)	Voltage magnitudes with MTG system connected at node 5 and Diesel Generator connected to node 9 (pu)
1	1.0000	1.0000
2	0.9943	0.9967
3	0.9890	0.9940
4	0.9806	0.9901
5	0.9698	0.9862
6	0.9665	0.9853
7	0.9637	0.9835
8	0.9553	0.9790
9	0.9473	0.9760
10	0.9445	0.9732
11	0.9436	0.9724
12	0.9434	0.9722

8. CONCLUSIONS

In this work the dynamic analysis of Split-shaft microturbine coupled with synchronous generator and Diesel Generator has been studied considering both P-I type of load following controller and P-I type of speed controller. The study reveals that both split-shaft MTG system and Diesel Generator system works very well in stand-alone mode of operation. Both the generating units are capable to meet the load demand and supply active power to the load. When load demand is higher than the generating capacity of a single generating unit (MTG/Diesel Generator system) then more than one generating unit can be connected together to meet the require load demand. For this purpose, MTG and Diesel Generator can be connected together and from this study it has been found that they together work very well.

Dynamic responses of split-shaft MTG and Diesel Generator systems have also been examined when they are connected to a rural distribution network. From the analysis it was found that during transient imbalance, they perform well and improve the voltage profile of the distribution network and reduce the active power loss of the network at steady state.

REFERENCES

[1] T. Ackermann, G. Andersson, L. Soder, “What is distributed generation ?”, 31st North American Power Symposium, Sab Luis Obispo, USA, pp. 232-239, 11-12 October 1999
[2] M. Suter, “Active filter for a microturbine ”, in Proc. Inst. Electrical engineering, Telecom energy conference (INTELEC2001), Edinburgh, UK, pp. 162-165, 2001.
[3] D. K. Nichols and K. P. Loving, “assessment of microturbine generators”, in Proc. IEEE PESGM, vol. 4, pp. 2314-2315, July 2003.
[4] J. Peirs, D. Reynaerts and F. Verplaetsen, “A microturbine for electric power generation”, Sensor Actuators, vol. 113, pp. 86-93, 2004.
[5] Y. Zhu, and K. Tomsovic, “Development of models for analyzing the load-followingperformance ofMicroturbines and fuel cells,” *Electric Power System Research*, vol.62, pp. 1-11, May 2002.
[6] M. Y. El-Sharkh, N. S. Sisworahardjo, M Uzunoglu, O. Onar and M. S. Alam, “Dynamic behavior of PEM fuel cell and Microturbine power plants”, Journal of Power Sources, vol.164, pp. 315-321, 2007.
[7] F. Jurado and J. R. Saenz, “ Adaptive control of a fuel cell – microturbine hybrid power Plant ”, *IEEE Transactions on Energy Conversion*, vol. 18, no. 2, pp. 342-347, June 2003.
[8] A. Bettani, C. Bossi, F. Fornari, S. Massucco, S. Spelta and F. Tivegna, “A microturbine generation system for grid connected and islanding operation”, *Proc. IEEE Power System Conf. Expo. (PES)*, vol. 1, pp. 360-365, October 2004.
[9] J. C. Ho, K. J. Chua, S. K. Chou, “Performance study of a microturbine system for cogeneration application”, Renewable Energy, vol. 29, pp. 1121-1133, 2004.
[10] A. K. Saha, S. Chowdhury, S. P. Chowdhury, and P. A. Crossley, "Modeling andperformance analysis of a microturbine as a distributed energy resource," *IEEE Transactionson Energy Conversion*, vol.24, no. 2, pp.529-538, June 2009.
[11] PB Malatestas, MP Papadopoulos, G Stavrakakis. “Modelling and identification of diesel–wind turbinessystems for wind penetration assessment.”IEEE Trans. on Power System, vol. 8, issue 3, pp. 1091-1097, 1993.
[12] Stavros A Papathanassiou and Michael P Papadopoulos, “Dynamic characteristics of autonomous wind–diesel systems” , *Renewable Energy*,Volume 23, Issue 2, pp. 293–311, June 2001,
[13] E. S. Abdin, A. M. Osheiba, and M. M. Khater, “Modeling and optimal controllers design for a stand-alone photovoltaic- diesel generator unit”, IEEE Trans. on Energy Conversion, vol. 14, No. 3, pp. 560-565, September 1999.

[14] A. Al-Hinai, and A. Feliachi, " Dynamic model of a microturbine used as a distributed generator," *in Proc. IEEE System Theory*, pp. 209-213, March 2002.

[15] M. Kalantar, S. M. Mousavi G,"Dynamic behaviour of a Stand-alone hybrid power generation system of wind turbine, microturbine, solar array and battery storage". Applied Energy,vol. 87, No. 10, pp. 3051-64, 2010.

[16] M. A. Rahman, A. M. Osheiba, T. S. Radwan, and E. S. Abdin, "Modeling and controller desigh of an isolated diesel engine permanent magnet synchronour generator", IEEE Trans on Energy Conversion, vol. 11, No. 2, pp. 324-330, June 1996.

[17] TomonobuSenjyu, Toshiaki Nakaji, Katsumi Uezato, andToshihisa Funabashi, "A hybride power system using alternative energy facility in isolated island", IEEE Trans. on Energy Conversion, vol. 20, No. 2, pp. 406-414, June 2005.

[18] J. A. M. Bleijs, "Wind turbine dynamic response difference between connection to large utility network and isolated diesel micro-grid", IET Renewable Power Generation, vol. 1, issue 2, pp. 95-106, June 2007.

[19] M. Nagpal, A. Moshref, G. K. Morison,"Experience with testing and modeling of gasturbines" In: Proc IEEE/PES, Winter Meeting2001, Columbus, Ohio, USA, vol.2, pp. 652-6, 2001.

[20] O. I. Elgerd,"Electric energy systems theory an introduction" New Delhi: TataMcGraw Hill, 1983.

[21] D. Das,"Electrical power systems", New Age International (p) Limited Publication, 2006.

[22] D. Canever, G. J. W. Dudgeon, S. Massucco, J. R. Mc Donald, and F. Silvestro, "Model validation and coordinated operation of a photovoltaic array and a diesel power plant for distributed generation", Power Engineering Society Summer Meeting, 2001, vol. 1, pp. 626-631, 2001.

APPENDIX

TABLE –2: Parameters of split-shaft MTG system model

Parameters	Representation	Value
P_r	Rated Real power generation capacity	250 kW
T_1	Fuel system lag time constant 1	10.0 s
T_2	Fuel system lag time constant 2	0.1 s
T_3	Temperature control loop lag time constant	3.0 s
K_g	Low value gate	0.7
K_t	Temperature control loop gain	1.0
D	Damping of generator	0.667
H	Inertia of generator	0.86
V_{max}	Maximum value position	1.2
V_{min}	Minimum value position	-0.1
L_{max}	Temperature control loop reference	1.2
K'_p	Proportional gain of load following controller	-3.5
K'_i	Integral gain of load following controller	-6.0
K''_p	Proportional gain of speed controller	-0.4
K''_i	Integral gain of speed controller	-0.85

TABLE– 3: Parameters of Diesel generator

Parameters	**Representation**	**Value**
P_{Drated}	Rated capacity of Diesel Generator	250kW
T_{sm}	Value actuator lag time constant	0.05 s
T_D	Diesel engine lag time constant	0.5 s
H_D	Inertia of Diesel Generator system	1.5
D_D	Damping of Generator system	0.667
f_0	Frequency	50 Hz
R	Droop of speed governor.	2.4
K'_{Dp}	Proportional constant of load-following controller.	-0.5
K'_{Di}	Integral constant of load-following controller	-0.3
K''_{Dp}	Proportional constant of load frequency controller	-0.3
K''_{Di}	Integral constant of load frequency controller	-0.2

TABLE– 4: Data of 12 node distribution network

Branch no.	Sending end node no.	Receiving end node no.	Branch resistance (ohm)	Branch reactance (ohm)	Active power load at receiving end node (kW)	Reactive power load at receiving end node (kVAr)
1	1	2	1.093	0.455	60	60
2	2	3	1.184	0.494	40	30
3	3	4	2.095	0.873	55	55
4	4	5	3.188	1.329	30	30
5	5	6	1.093	0.455	20	15
6	6	7	1.002	0.417	55	55
7	7	8	4.403	1.215	45	45
8	8	9	5.642	1.592	40	40
9	9	10	2.890	0.818	35	30
10	10	11	1.514	0.428	40	30
11	11	12	1.238	0.351	15	15