POWER CONDITIONING FOR GRID CONNECTED MICROTURBINE GENERATION USING MATRIX CONVERTER TECHNIQUE

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ABSTRACT

Micro turbines are widely popular as generating units in 'Distributed Generation' systems and as energy producers in Combined Heat Power systems. Micro turbines are small and simple cycle gas turbines. Micro turbines are available as single shaft and split shaft units. In Micro grids a micro turbine is interfaced with a synchronous machine for power generation. Power generated by micro turbines is at some undesirable frequency. So power electronic interface is required to deliver power at required frequency. Convention Micro turbines use rectifier-inverter interface for AC-AC conversion. This interface utilizes a DC link capacitor as a temporary energy storage device. This link is of large in size and has less life. Conventional interface induces more harmonics due to frequent switching of power electronic elements. So in order to eliminate these, a Matrix Converter interface is being used in the project. The Matrix Converter is an array of controlled semi conductor switches that connects directly the three phase source to three phase load. It does not require any dc-link circuit and does not need any large energy storage elements.

Index Terms- Distributed Generation, Micro Turbine, Permanent Magnet Synchronous Generator, Power Conditioning Unit, Filter, Islanding Mode, Grid Connected Mode.

I. INTRODUCTION

The integration DG systems into the main electricity network is currently changing the paradigm we used to live with, where the electric power was generated in large power plants, sent to the consumption areas through transmission plants, sent to the consumption areas through transmission lines, and delivered to the consumers through a passive distribution infrastructure. The integration of DG into distribution networks in recent years has transformed them from being passive to active networks [1]. The progress of DG, as an important energy option in the present scenario is the result of combination of utility restructuring, technology\evolutions and recent environmental policies, Distributed or embedded generator is generally defined accepted as a plant which is connected directly to utilities distribution network or can operate independently. They are generally considered to be less than 100MW in capacity and are not centrally planned or dispatched. Distributed generation can be based on renewable technologies such as wind turbine, photovoltaic or recent promising non renewable technologies such as micro turbine and fuel cell. Distributed generation using micro turbine is a typical and practical solution because of its environment-friendliness and high energy efficiency [2].Various applications such as peak saving, co-generation, remote power and premium power will make its penetration wide spread. Once connected to the power distribution system, these generators will affect the dynamics of the system whose transient behaviour can be assessed only if a detailed nonlinear dynamic model is used. Thus, an accurate model of the MTG system is required to analyze the factors such as transient response, stability, power quality including harmonics, voltage regulation and protection, when connected to distribution network. Until now, only few works were undertaken on the modelling, simulation and control of MTG systems. There is also a lack of adequate information on their performances. A dynamic model for combustion gas turbine has been discussed in some of the previous works [3]-[6]. In these references, a combustion gas turbine 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 dynamic model of micro turbine generation system for isolated operation is developed in [7]-[8] A linearised modelling of grid connected micro turbine generation system is reported in [9]. The dynamic behaviour of the grid connected split shaft micro turbine generation system is presented in [10]. The evaluation of the electromagnetic transients of a grid connected MTG system that includes an AC-DC-AC converter is done in [11]. Modelling of micro turbine and its advanced controls for both grid-connected and islanding conditions with privileged loads are developed and presented in [12]. These methods deals with unidirectional power flow between the MTG system and distribution network. In these models the MTG-side converter is a diode-rectifier, a thyristor-rectifier or a Voltage-Sourced Converter (VSC) and the utility side converter is often a VSC unit. The modelling of power electric interface for grid connection of MTG system is presented in [13]. In this paper a single shaft MTG system model is developed in Simulink/SimPower Systems of the MATLAB .The developed model considers bidirectional power flow between the grid and MTG system. Two interface controls are designed; one normal for island operation are given. The extensive simulation is carried out to study the performance of the model when connected to the distribution network.

II. MICRO TURBINE GENERATION SYSTEM 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 4000 Hz. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage.

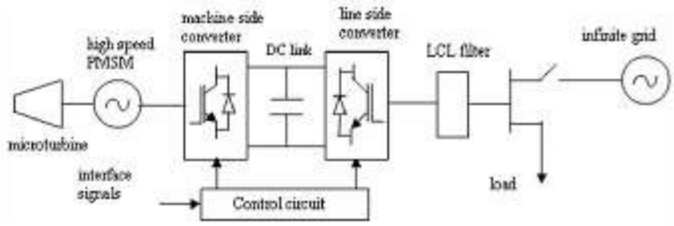

Fig. 1. Micro Turbine Generation System (MTGS) Another Is A Split-Shaft Design That Uses A Power Turbine

Another is a split-shaft design that uses a power turbine rotating at 3600 rpm and a conventional generator (usually induction generator) connected via a gearbox. The power electronic interfacing is 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 micro turbine generation systems

2.1 Micro Turbine

The model consists of fuel control, turbine dynamics, and speed governor blocks. The electromechanical behaviour is of main interest in this work. Therefore, the recuperator and the heat exchanger unit are not included in the model as it only serves to increase the turbine efficiency. The speed control operates on the speed error formed between reference (one per-unit) speed and the MTG system rotor speed. It is the primary means of control for the micro turbine under part load conditions [8]. The model parameters are given in Appendix [5]. Speed control is usually modelled by using a lead-lag transfer function or by a PID controller [3]. In this work a lead lag transfer function has been used to represent the speed controller. The governor controls are shown in the Fig. 2 with parameters X, Y, Z and gain (K), which can be adjusted so that the governor can act with droop or as isochronous governor. Acceleration control can be used primarily during turbine start-up to limit the rate of the rotor acceleration prior to reaching operating speed. The output of the governor goes to a low value select to produce a value for the fuel demand signal. The other signal into the low value select is from the temperature controller which is not considered here. The per unit value for fuel demand signal, corresponds directly to the per unit value of |mechanical power on turbine base in steady state. The fuel flow control system consists of series of blocks including the valve position and flow dynamics. The value of fuel demand signal is scaled by the gain value of 0.77 and offset by value which is the fuel flow at no load, at rated speed condition. The time delay preceding the fuel flow control represents delay in the governor control using digital logic in place of analog devices. The fuel burned in the combustor results in turbine torque.

2.2 Permanent Magnete Synchrones Machine (PMSM)

The model adopeted for the generator is a 2 pole permanent magnet synchronous machine (PMSM) with a non-salient rotor. At 1600 Hertz (96 000 rpm), the machine output power is 30 kW and its terminal line-to-line voltage is 480 V. The electrical and mechanical parts of the machines 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) are used to implement PM synchronous machine.

Electrical system:

$$\frac{d}{dt}i_d = \frac{1}{L_d}v_d - \frac{R}{L_d}i_d + \frac{L_q}{L_d}p\omega_r i_q \tag{1}$$

$$\frac{d}{dt}i_q = \frac{1}{L_q}v_q - \frac{R}{L_q}i_q - \frac{L_d}{L_q}p\omega_r i_d - \frac{\lambda p\omega_r}{L_q} \tag{2}$$

$$T_e = 1.5p\,(\lambda i_q + (L_d - L_q)i_q i_d) \tag{3}$$

Mechanical system:

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - F\omega_r - T_M) \tag{4}$$

$$\frac{d}{dt}\theta = \omega_r \tag{5}$$

Where

Lq, Ld: q and d axis inductances

R : Resistance of the stator windings

Iq, id : q and d axis currents

Vq, Vd: q and d axis voltages

Tm : Shaft mechanical torque.

2.3 Power Conditioning

The power conditioning is a critical component in the single- shaft micro turbine design and represents significant design challenges, specifically in matching turbine output to the required load. There are different configurations available for this purpose. One possibility is to use a three-phase diode rectifier, a voltage source inverter (VSI) and filter. This requires separate start up inverter during starting. The configuration used in this paper uses back to back voltage source converters (VSC). This topology allows bi-directional power flow between the converter and the grid and hence no separate starting arrangement is required. During the starting PMSM acts as motor and draws power from the grid to bring the turbine to certain speed. In this line side converter acts as controlled rectifier and machine side converter acts as inverter and provides AC supply to the motor; this is also referred as motoring mode of operation of PMSM. During the generating mode PMSM acts as generator and power flows from MTGS to grid. The machine side and line side converters act as controlled rectifier and inverter respectively. In both the mode of operation the grid-side converter regulates the DC bus voltage while the machine-side converter controls the PMSM speed and displacement factor. This control structure decouples effectively the two converters control scheme. Synchronization of the grid-side converter is carried out by a phase lock loop (PLL). Both converters use PWM modulation technique. Depending on the status of the MTG system two different control strategies for the line side converter have been considered: PQ control strategy with dc voltage control is used for grid connected mode of operation and voltage /frequency control for stand alone or islanding Operation mode.

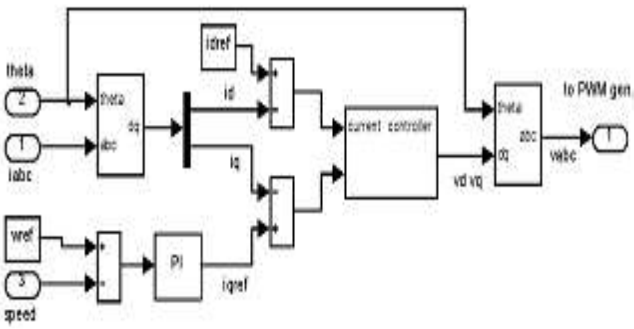

Fig. 2. Machine Side Converter Control

2.3.1 Machine Side Converter Control

Fig. 2 shows high efficiency drive control system for the MTG. The commanded peed oref is pre-calculated according to the turbine output power and set to the optimum speed. Based on the speed error the commanded q axis magnetizing current iqref is determined through the speed controller. In this system the following PI controller is employed as the speed controller

$$i_{qref} = K_{p\omega} e_{\omega} + K_{i\omega} \int e_{\omega} dt \qquad (6)$$

Where, Kpe, and KC,, are the proportional and integral gains respectively. The commanded d axis current idref is pre- determined and set to the optimum magnetizing current value. Based on the current errors, the commanded dq-axes voltages are determined through the current controller. In this system, the following PI controllers with decoupling terms are utilize for the current controllers.

$$v_d = K_{pi} e_d + K_{ii} \int e_d dt - w_r L_q iq \qquad (7)$$

$$v_q = K_{pi} e_q + K_{ii} \int e_q dt + \omega_r (L_d i_d + \lambda) \qquad (8)$$

The commanded dq-axes voltages (vd, vq) are transformed into the abc quantities (Va, Vb, Vc) and given to PWM generator to generate the gate pulse.

2.3.2 Line Side Converter Control

The MTG system line side converter can operate both in grid connected control mode and stand alone control mode.

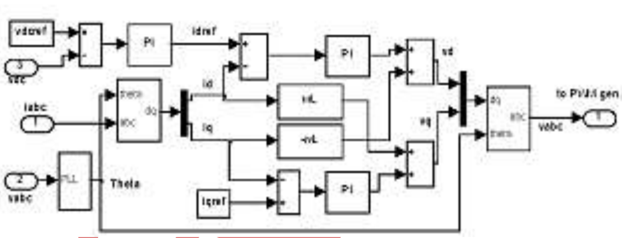

Fig. 3 Line Side Converter Control for Grid Connected Mode

2.3.3 Grid Connected Mode

The control structure for grid-connected mode is shown in Fig. 3. The grid-side converter operates as a controlled power source. The standard PI-controllers are used to regulate the grid currents in the dqsynchronous frame in the inner control loops and the dc voltage in the outer loop. It is seen that a PI controller regulates the DC bus voltage by imposing an Id current component. Id represents the active component of the injected current into the grid and 'q is its reactive component. In order to obtain only a transfer of active power, the iq current reference is set to zero. The decoupling terms are used to have independent control of id and iq in. A PLL is used to synchronize the converter with the grid. The philosophy of the PLL is that the difference between grid phase angle and the inverter phase angle can be reduced to zero using PI controller, and thus locking the line side inverter phase to the grid.

2.3.4 Island Operation Mode

In island control mode, no grid exists so the output voltages need to be controlled in terms of amplitude and frequency and thus, the reactive and active power flow is controlled. The control structure for islanding control mode is depicted in Fig. 4. It consists of output voltage controller and dc-link voltage controller. The output voltage controller will control the output voltage with a minimal influence from the shape of the load currents or load transients.

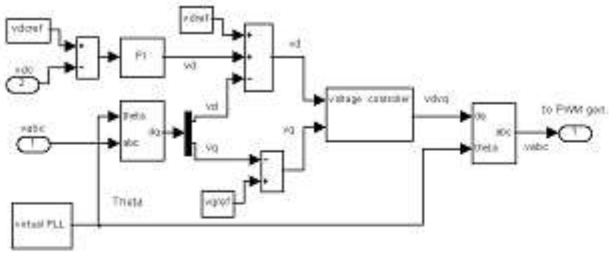

Fig. 4. Line Side Converter Control for T Iislaningamoe

A standard PI controller operating in the synchronously rotating coordinate system where vq is kept to zero is used. The dc-voltage PI controller maintains the dc voltage to the reference. The dc-link voltage controller is acting only when the dc-link is below the reference and it lowers the voltage reference of the main voltage controller in order to avoid inverter saturation. For fast response there is a direct forward connection to the voltage controller output. The frequency regulation has been done using virtual PLL block, which is available in the SimpowerSystems. D. Filter Design The primary function of the AC filter is to filter out the high n frequency components caused by the inverter switching operation. However, the filter also affects the low order harmonic performance of the system. In this paper LCL filter is used for Grid side T converter. The passive LCL filter design used for Grne side sidverter control for islandie Fig 7depends on the attenuation needed in order to reduce the high frequency component of the line current. Standards such as IEG 1000-3-4 regulation on current harmonic emissions into the power grid, must be used to rate this attenuation. The IEG 1000-3-4 regulation states that current harmonics above the 33rd should be less than 0.60o of the nominal current. The transfer function of the LCL Filter designed by the output voltage to the input Current is given as follows.

$$G^{\alpha\beta}(s) = \frac{\frac{1}{L_1 L_2 C}}{s\,(s^2 + \frac{L_1 + L_2}{L_1 L_2 C})} \tag{9}$$

Where, the series resistance of the inductors is neglected for simplicity. Using the above equation and considering resonance frequency and low ripple current, inductors values are determined. In addition the capacitor value is rated with the accepted reactive power level of the capacitor for LCL filters. The procedures for designing of LCL filters are given .In this model for LCL configuration supply side (L1) and inverter side inductance (L2) values are lmH and 6.5mH.

III. 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 [5,6]. A common matrix converter structure consisting of 3x3 switches is shown in Fig. 5. As can be seen, it connects a three-phase voltage source to a three-phase load [6]. 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.

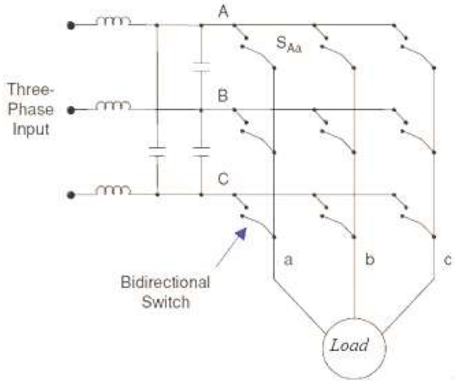

Fig. 5. Basic Mc Structure

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 [5]. Considering Fig. 5 and defining the switching function of a single switch as [5]:

$$S_{Kj} = \begin{cases} 1 & switch\, S_{Kj}\ closed \\ 0, & switch\, S_{Kj}\ open \end{cases}$$

$$K = \{A, B, C\} \qquad j = \{a, b, c\} \tag{10}$$

$$S_{Aj} + S_{Bj} + S_{Cj} = 1, \quad j = \{a, b, c\} \tag{11}$$

The load and source voltages of Fig. 3 with reference to supply neutral are considered as follows:

$$V_o = \begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} \qquad V_i = \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix} \tag{12}$$

So, it can be written that:

$$\begin{bmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{bmatrix} = \begin{bmatrix} S_{Aa}(t) & S_{Ba}(t) & S_{Ca}(t) \\ S_{Ab}(t) & S_{Bb}(t) & S_{Cb}(t) \\ S_{Ac}(t) & S_{Bc}(t) & S_{Cc}(t) \end{bmatrix} \begin{bmatrix} v_A(t) \\ v_B(t) \\ v_C(t) \end{bmatrix}$$

$$V_o = T.V_i \tag{13}$$

Where T is the instantaneous transfer matrix.

In order to derive modulation rules, it is also necessary to consider the switching pattern that is employed.

IV. MATLAB/SIMULINK RESULTS

The model used for study the performance of MTG system in Grid connected/islanding mode is shown in Fig. 6. The distribution network, to which MTG system is connected, is represented by balanced 3 phase source.

APPENDIX

The Speed governor parameters: Gain (K) =25, X=0.4,

Y=0.05, Z=1.

Parameters of PMSM: Rs = 0.25 Ω, No. of poles = 2,

Ld = Lq= 0.6875 mH, X =0.0534 wb.

Grid parameters: R=0.4 Ω, L=2mH, 480V, 60Hz.

Load parameters: 25 kW, 480 V, Load parameters: 25 kW, 480 V, 60 Hz.

Case1: study the performance of MTG system in Grid connected.

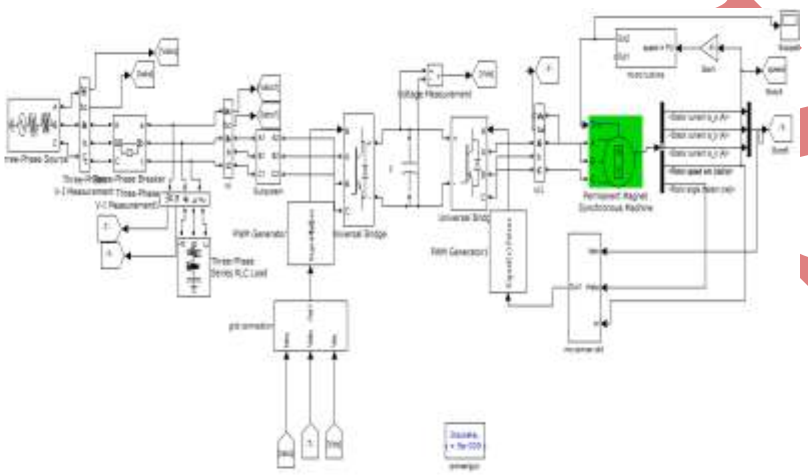

Fig. 6.Simpowersystems Implantation of MTG System

Figure6 shows the simpowersystems implantation of MTG system study the performance of MTG system in Grid connected.

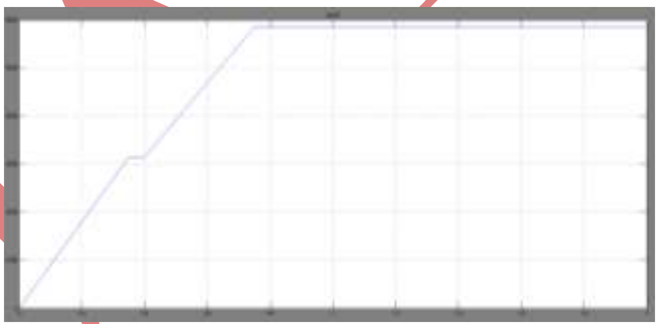

Fig. 7. Speed variation of PMSM

Figure7 shows the speed variation of PMSM the model used for study the performance of MTG system in Grid connected

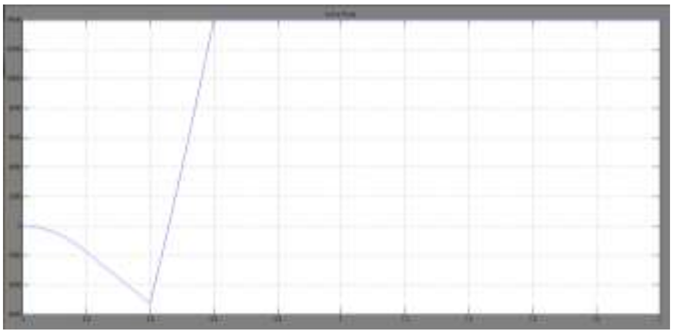

Fig. 8. Active power variation during motoring /generating mode at the grid side of MTG system

Figure8 shows the Active power variation during motoring generating mode at the grid side of MTG system

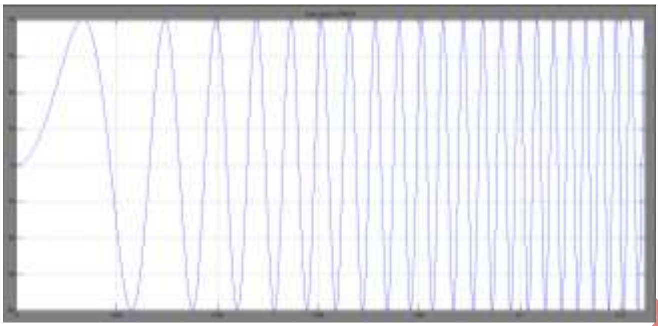

Fig. 9. Line current of PMSM in generating mode at 14 kW

Figure9 shows the Line current of PMSM in generating mode at 14 kW.

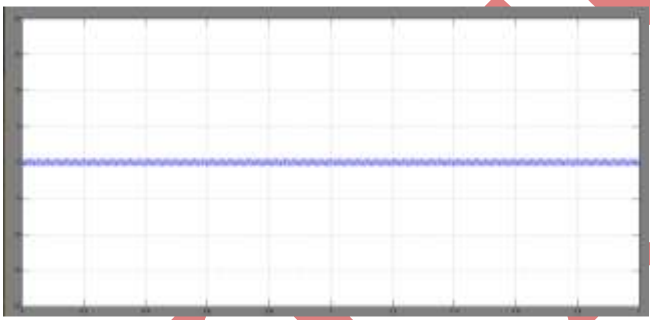

Fig. 10. Current iq injected into the grid

Figure10 shows the Current iq injected into the grid.

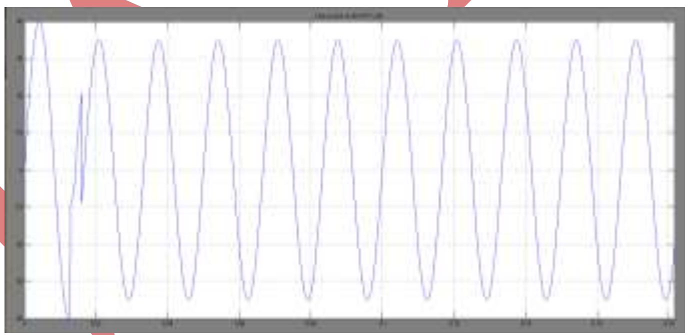

Fig. 11. Line current at the MTG side of the interface

Figure11 shows the Line current at the MTG side of the interface.

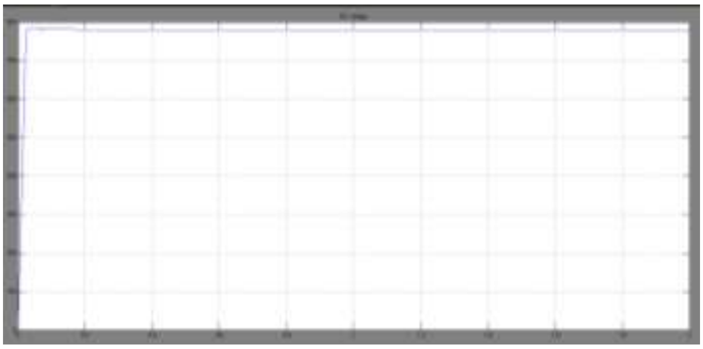

Fig. 12. DC link voltage

Figure12 shows the DC link voltage.

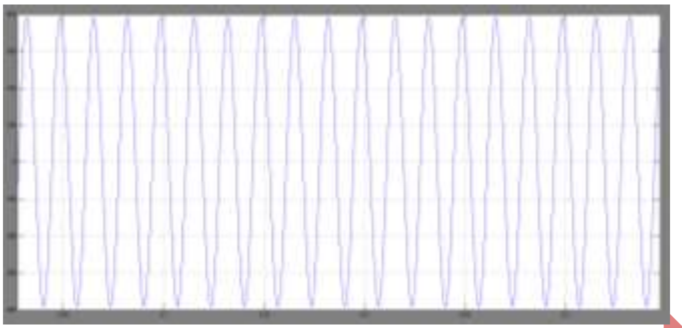

Fig. 13. Voltage across the load terminals

Figure13 shows the Voltage across the load terminals.

Case2: PMSM with matrix converter

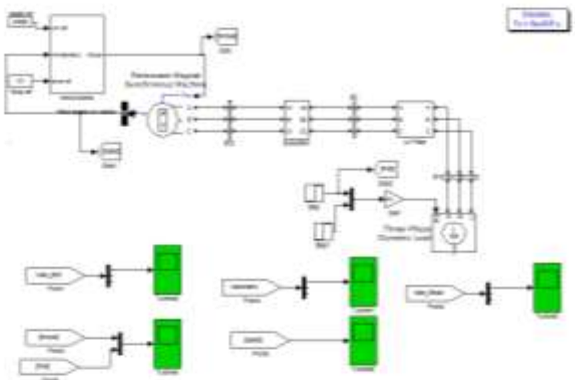

Fig. 14. PMSM with matrix converter

Figure14 shows the performance of the model is studied for different values of reference output power side of MTG system.

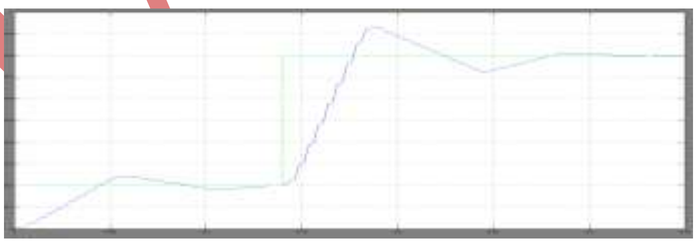

Fig. 15. Speed variation of PMSP

Figure15 shows the speed variation of PMSP with matrix converter

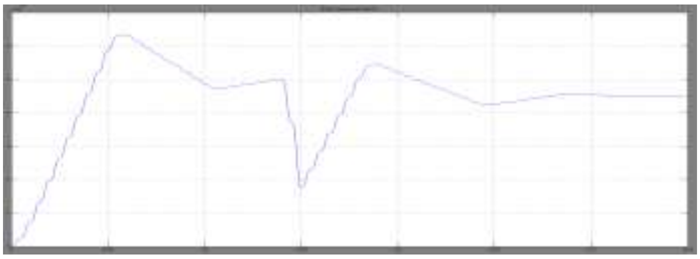

Fig. 16. Speed of MTG system

Analysis: As the load is initially 0.2 the speed of micro turbine increases from zero and goes to its maximum value and then attains a constant speed. But when load has suddenly increase at 0.14 sec the speed decreases at this instant and then it automatically adjust itself with the help of speed governor and attains its normal operational speed again.

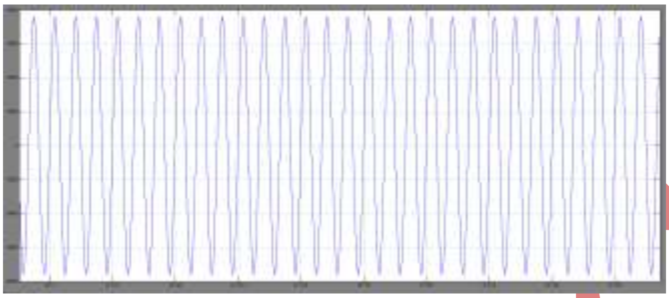

Fig. 17. PMSG output voltage at 0.2 loads (pu)

Figure17 shows the PMSG output voltage at 0.2 loads (pu).

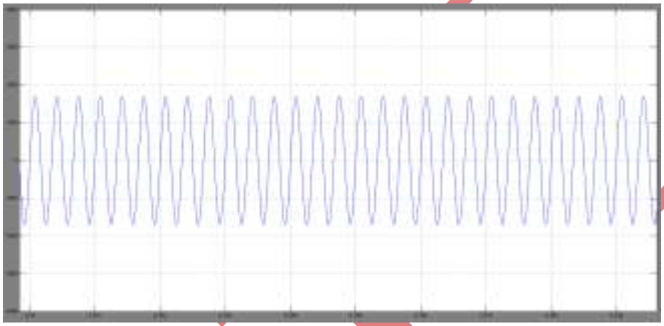

Fig. 18. PMSG output voltage at 0.8 load (pu)

Analysis: At fist when the load is 0.2 pu the PMSG attains certain voltage and when the load has increased there is a slight decrease in the voltage of PMSG.

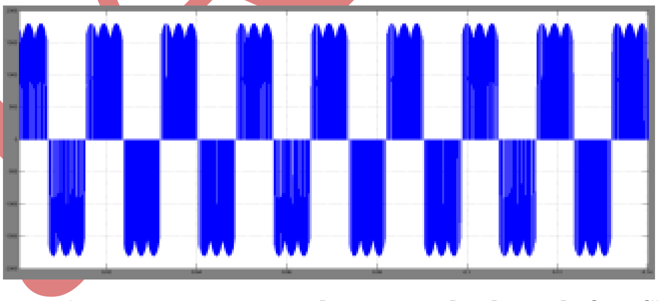

Fig. 19. Matrix converter output voltage at 0.2 loads pu (before filtering)

Figure19 shows the Matrix converter output voltage at 0.2 loads pu (before filtering).

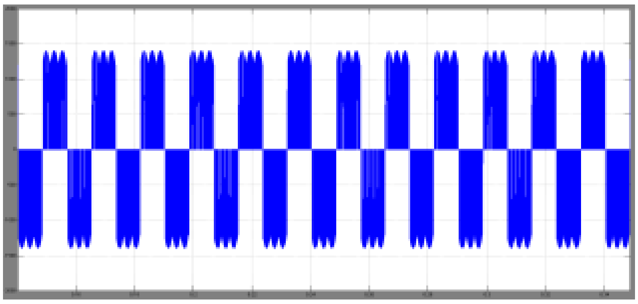

Fig. 20. Matrix converter output voltage at 0.8 load pu (before filtering)

Figure20 shows the Matrix converter output voltage at 0.8 load pu (before filtering).

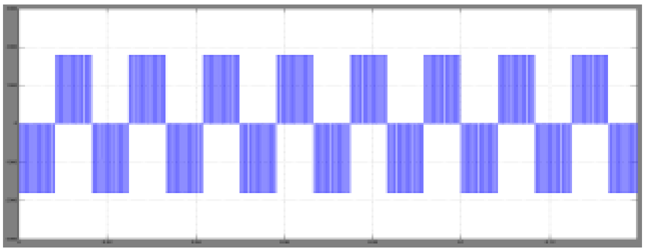

Fig. 21. Conventional Converter output voltage at 0.2 load pu (before filtering)

Figure21 shows the Conventional Converter output voltage at 0.2 loads pu (before filtering).

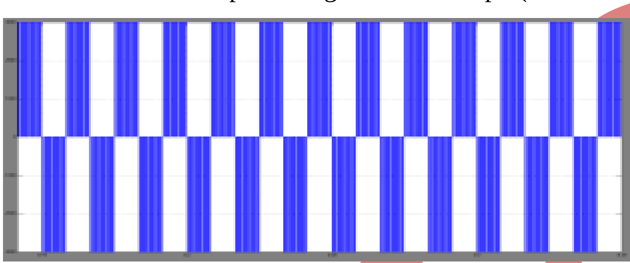

Fig. 22. Conventional Converter output voltage at 0.8 load pu (before filtering).

Analysis: Before filtering some harmonics will be present in the output voltages of both matrix and conventional converters which can be eliminated by using filters.

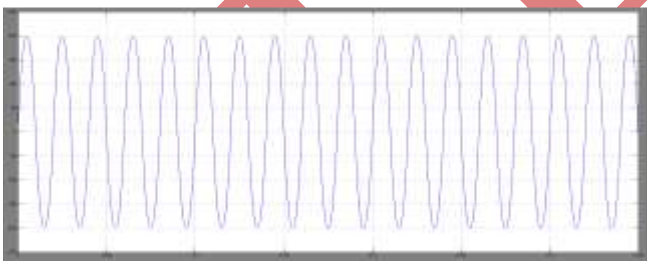

Fig. 23. Load terminal Voltage of Matrix converter

Figure23 shows the Load terminal Voltage of Matrix converter

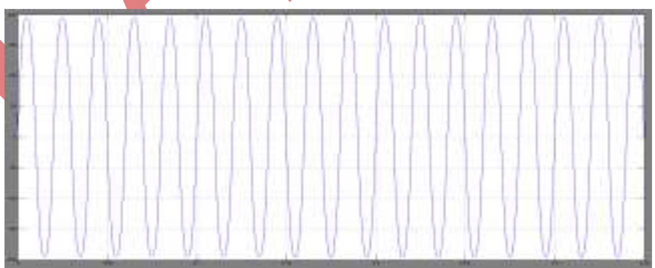

Fig. 24. Load Terminal Voltage of Conventional Converter.

Analysis: After the filter is included in the circuit the harmonics are eliminated from the circuit.

V. CONCLUSION

Micro turbine generation system has a capability to automatically adjust itself to the changes in load. It controls the speed, fuel flow, acceleration of turbine and also its temperature to its set values. Since these are small and simple gas turbines, they can be installed at the load site itself and so the transmission losses can be reduced to some extent. They can simultaneously serve small loads and deliver power to the mains grid when the micro turbine is connected to the grid as studied in the previous project.

The micro turbine generation system delivers low quality power to the load due to the presence of harmonics when the conventional converters are used. These harmonics are induced due to the frequent switching operations in the converters. The total harmonic distortion is more in this case. So to avoid these consequences matrix converter is proposed for the micro turbine generation system for AC-AC conversion. This has fewer harmonic induced than the conventional conversion process. And hence it delivers high quality power to the load.

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