CHAPTER 5: **TIME DEPENDENT MODELLING OF MHD GENERATOR AND TRANSIENT RESPONSE OF THE MHD-GENERATOR INVERTER LINK**

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CHAPTER 5

TIME DEPENDENT MODELLING OF MHD GENERATOR AND TRANSIENT RESPONSE OF THE MHD GENERATOR INVERTER LINK**

5.1 Introduction

The V-I characteristics of the MHD duct has been assumed linear for all calculations in the previous chapters. In this chapter, time dependent modelling of the duct yields actual characteristics. The V-I characteristics obtained in this chapter are for a 2 MW (thermal) MHD generator. The power control of the duct now utilizes these characteristics.

The transient operation of the MHD duct is complicated and has been receiving attention only in recent years [72-75]. The calculations made by Oliver ([73] for a segmented Faraday generator show that when a sudden load is imposed on the generator, a strong shock development takes place. Such fast fluid dynamic transient for sudden load disturbances will have adverse effects on the power system as a whole. Therefore, more details are needed for integration of MHD generator with power system under transient state. A voltage source inverter

** The material presented in this chapter has led to the authors publication number 9, 10 and part of publication number 2.
(VSI) is used in this chapter for the transient analysis of the MHD-inverter link. A set of current and voltage equations are derived to predict the transient behaviour of the MHD duct with gas dynamic coupling.

5.2 MHD fluid flow equations

The equations describing particular flow conditions are usually these derived from the conservation quantities i.e. conservation of mass (equation of continuity), conservation of momentum (equation of motion) and energy conservation. For plasma flow in e.m. field these equations are derived by Sutton and Sherman [76]. They describe the motion of a compressible, viscous fluid using conservation principles and Maxwell's equations assuming nonrealistic motion.

Conservation of mass principles results in:

\[ \frac{\partial \rho}{\partial t} + \rho \nabla \cdot \mathbf{V} = 0 \]  \hspace{1cm} \text{(5.1)}

where \( \rho \) = mass density of the plasma
\( \mathbf{V} \) = velocity vector for the flow

Conservation of momentum:

\[ \rho \frac{D\mathbf{V}}{Dt} + \nabla \cdot \mathbf{T} + \nabla \cdot \mathbf{p} = \rho \mathbf{e}_e \mathbf{E} + \mathbf{j} \times \mathbf{B} \]  \hspace{1cm} \text{(5.2)}

where \( \mathbf{T} \) = shear stress vector
\( P \) = hydrostatic pressure
\( \rho_e \) = charge density
\( \vec{E} \) = electric field vector
\( \vec{B} \) = Magnetic field vector
\( J \) = Electric current density

Note: \( \frac{D}{Dt} = \frac{\partial}{\partial t} + \nabla \)

Conservation of energy:

\[
\rho \left( \frac{D(e + \frac{\vec{V}^2}{2})}{Dt} \right) = -\nabla \cdot \vec{q} - \nabla \cdot (\rho \vec{V}) - \nabla \cdot (\rho \vec{V}) + \vec{E} \cdot \vec{J} \tag{5.3}
\]

where \( e \) = internal energy of the plasma
\( \vec{q} \) = heat flux vector

The general form of the fluid flow equations (5.1) to (5.3) are complex to solve. Therefore for ease of solution they are approximated and verified by the numerical analysis in section 8.3 of Sutton and Sherman [76]. With the above MHD approximations they can be written as

Conservation of Mass

\[
\frac{\partial \rho P}{\partial t} + \nabla \cdot (\rho \vec{V}) = 0 \tag{5.4}
\]

Conservation of Momentum

\[
\rho \frac{D\vec{V}}{Dt} = -\nabla P + \nabla \cdot \vec{J} + \vec{J} \times \vec{B} \tag{5.5}
\]

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where \( \mathbf{\tau} \) = Viscous force vector

Conservation of Energy

\[
\rho \ \frac{D(e + \frac{v^2}{2})}{Dt} = \mathbf{j} \cdot \mathbf{E} - \nabla \cdot q - \nabla \cdot (\mathbf{F} \mathbf{V}) + \phi
\]  

(5.6)

where \( \phi \) = viscous dissipation function

5.3 Quasi-one dimensional flow equations

MHD process for generating power is inherently three dimensional. The quasi one dimensional approximations permit the reduction of the three dimensional MHD equations to a simpler system of first order ordinary differential equations for the ease of numerical solution [77-80]. The following assumptions are made for the solution of quasi-one dimensional flow equations for linearly diverging segmented Faraday generator as shown in figure 5.1.

(i) The velocity vector, \( \mathbf{v} \), has only one component, \( u \) in the \( x \) direction and applied magnetic field is in \( z \) direction only. Due to fine segmentation, the electric field is only in \( Y \) direction.

(ii) Non uniformities at the exit and entrance to the duct caused by the end effects are neglected.

(iii) Fluid variables such as pressure, temperature, density, conductivity and velocity are considered to be
FIG. 5.1. LINEAR MHD GENERATOR.
reasonably constant over a transverse (Y-Z) cross section.

The quasi-one dimensional equations can now be derived on the basis of these assumptions [80-81]. From the third assumption many of the flow parameters are taken as constant over a cross section so that the constant value taken over the cross sectional area is the average value at any time. In this way such parameters vary only with axial position along the duct (i.e. in X direction) and with time.

Applying the approximations to equations (5.4), (5.5) and (5.6) the following quasi one dimensional relations are obtained.

Conservation of Mass:

\[
\frac{\partial \bar{\rho}}{\partial t} + \frac{\partial (\bar{\rho} \bar{u})}{\partial x} = 0 \tag{5.7}
\]

Conservation of Momentum:

\[
\frac{\partial \bar{\rho} \bar{u}}{\partial t} + \frac{\partial \bar{\rho} \bar{u}^2}{\partial x} = -A \frac{\partial \bar{P}}{\partial x} + A \frac{\partial J_y}{\partial x} B_z + \bar{F}_b \tag{5.8}
\]

where \( F_b \) = Wall friction term due to shearing stress on the wall

Conservation of Energy:

\[
\frac{\partial \{A \bar{\rho}(u^2/2 + e)\}}{\partial t} + \frac{\partial \{A \bar{\rho}(u^2/2 + e)\}}{\partial x} = -\frac{\partial \bar{\rho} \bar{u}}{\partial x} + A \bar{E}_y J_y + A Q_T \tag{5.9}
\]
where \( Q_T \) = heat transfer term due to viscous dissipations,  
heat loss by conduction and heat addition by  
chemical reaction

Dropping the bar notation to denote average values and  
introducing the momentum density \( m = \rho u \) and the total energy  
density \( e_t = \rho (e + u^2/2) \) the equations (5.7), (5.8) and (5.9)  
take the form

\[
\begin{align*}
\frac{\partial e}{\partial t} &= - \frac{\partial \bar{m}}{\partial x} - \frac{m}{A} \frac{\partial A}{\partial x} \\
\frac{\partial \bar{m}}{\partial t} &= - \frac{\partial (m^2/\rho + P)}{\partial x} - \frac{(m^2/\rho)}{A} \frac{\partial A}{\partial x} + J_B - F_b \\
\frac{\partial e_t}{\partial t} &= - \frac{\partial (e_t + P)m/\rho}{\partial x} - \frac{(e_t + P)m/\rho}{A} \frac{\partial A}{\partial x} + J_E u + Q_T
\end{align*}
\]

(5.10)

(5.11)

(5.12)

Expressions for \( F_b \) and \( Q_T \) are given in terms of the wall shear  
stress \( \tau \) and heat flux \([73]\].

\[
F_b = 4 \frac{\tau}{D_H} \\
Q_T = 4 \frac{\tau q}{D_H}
\]

where \( D_H \) is a constant and \( \tau \) and \( q \) are functions of the flow  
variables \( \rho, u \) and \( e \) related to boundary layer mechanics  
of the appropriate wall regions in the duct.
5.4 Theoretical model of the MHD generator [73]

In order to simplify the description of the flow in terms of mass, momentum and energy conservation equations for the quasi-one-dimensional equations (5.10), (5.11) and (5.12) may be rearranged and combined in vector notation to form a single vector equation. The vector functions \( \mathbf{U}(x,t) \), \( \mathbf{F(U)} \), \( \mathbf{H(U,x)} \), \( \mathbf{S(U,x,t)} \) and \( \mathbf{D(U,x,t)} \) are defined as in reference above.

\[
\mathbf{U}(x,t) = (\rho, m, e_t)^T \quad (5.13)
\]
\[
\mathbf{F(U)} = \{ m, (m^2/\rho) + p, (e_t + p)m/\rho \}^T \quad (5.14)
\]
\[
\mathbf{H(U,x)} = \frac{1}{A} \frac{\partial A}{\partial x} \{ m, m^2/\rho, (e_t + p)m/\rho \}^T \quad (5.15)
\]
\[
\mathbf{S(U,x,t)} = (0, 0, J_y B, J_y E_y)^T \quad (5.16)
\]
\[
\mathbf{D(U,x,t)} = (0, 0, F_b, Q_T)^T \quad (5.17)
\]

or, in the notation of Oliver [73]

\[
\mathbf{D(U,x,t)} = (0, 0, 4 \gamma_w/D_H, 4q_w/D_H)^T \quad (5.18)
\]

The equations (5.13) to (5.18) can be combined to form one single vector equation representing fluid state at any time \( t \) and position \( x \).

\[
\frac{\partial \mathbf{U}}{\partial t} = \frac{\partial \mathbf{F}}{\partial x} - \mathbf{H-D-S} \quad (5.19)
\]

There are a number of different techniques that may be
employed to obtain numerical solutions for partial differential equations of the form (5.19). The methods used in this case must hold for subsonic, supersonic and transonic conditions between such flow states. Currently one of the most popular methods used for evaluating the compressible flow relationship of the type under consideration involves a class of finite difference techniques called Lax-Wendroff methods. The particular type used in reference [37] is based on two-step Lax-Wendroff method devised by Richtmyer and modified by MacCormack.

This method is based on the replacement of the non-linear partial differential operator in equation (5.19) by a non-linear finite difference operator. The equation can be rewritten in the form

\[ \frac{\partial u(x,t)}{\partial t} = \frac{-\partial \left( f(u) \right)}{\partial x} - c(u,x,t) \]  

(5.20)

where \( c(u,x,t) = H(u,x) + S(u,x,t) + D(u,x,t) \)

The space and time co-ordinates within the duct are considered to be discretized into finite difference \( \Delta x \) and \( \Delta t \), where \( x = i \Delta x \) and \( t = n \Delta t \) where \( i \) and \( n \) are integers. In this way the fluid state \( U \) at a time \( t \) and position \( x \) can then be represented as \( U(x,t) = U^n_i \). The state of the fluid at a time \( \Delta t \) later i.e. \( U^n_{i+1} \) can be calculated from \( U^n_i \) using
the Richtmyer-MacCormack method. There are two steps required
in the process, the first of which involves the evaluation of
an intermediate state $u_1^{n+1}$ where

$$u_1^{n+1} = u_1^n - \frac{\Delta t}{\Delta x} \left\{ F(u_1^{n+1}) - F(u_1^n) \right\} - \Delta t \xi(u_1^n, x, t) \quad (5.21)$$

The second step allows the state $u_1^{n+1}$ to be determined
from the intermediate state and the state $u_1^n$.

$$u_1^n = \frac{1}{2} \left\{ u_1^{n+1} + u_1^n - \frac{\Delta t}{\Delta x} \left\{ F(u_1^{n+1}) - F(u_1^{n-1}) \right\} \right\} - \Delta t \xi(u_1^n, x, t) \quad (5.22)$$

In this way if an initial fluid state $u_1^0$ is given, the
subsequent fluid states may be computed forward in time through
the full subsonic, transonic and supersonic range.

To ensure the numerical stability of the relations
(5.21) and (5.22), it is necessary to satisfy the Courant
condition at each point where the fluid state is evaluated.
This criterion, described by Roache (82) requires that

$$C = \frac{(|u| + a) \Delta t}{\Delta x} \leq 1 \quad (5.23)$$

where $C =$ Courant number.

$u =$ local fluid velocity

$a =$ local sonic speed
Rearranging this criterion the restriction is imposed on $\Delta t$ that

$$\Delta t \leq \frac{\Delta x}{u + a} \quad (5.24)$$

Examination of equations (5.21) and (5.22) reveals that neither $U_N$ (i.e., the stream boundary (exit) fluid state where $(N-1)x =$ length of the channel) or $U_1$ (i.e., the upstream boundary (inlet) fluid state) can be calculated using the two-step finite difference method directly.

For the upstream boundary both $\rho_1^{n+1}$ and $\varepsilon_{t_1}^{n+1}$ can be calculated from the pressure and temperature specified under inlet conditions but $u_1^{n+1}$ is allowed to develop as part of the solution by using backward linear interpolation so that

$$u_1 = 2u_2 - u_3$$

and hence $m_1 = u_1 \rho_1$

At the downstream linear extrapolation enables both the density $\rho_N$ and momentum density $m_N$ to be calculated.

$$\rho_N = 2 \rho_{N-1} - \rho_{N-2} \quad (5.25)$$

$$m_N = 2 m_{N-1} - m_{N-2} \quad (5.26)$$

Then $\varepsilon_N$ is obtained from the imposed exit boundary conditions, $\rho_N$ and $m_N$. 

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5.5 **Electrical characteristics of the MHD generator**

The numerical technique described in section 5.4 is applied to a constant height duct with a rectangular cross sectional area. An analysis programme developed by Matalir [83] was modified to take into account the Hall effect and electrical characteristics were obtained for both Faraday and dologonal modes. The model includes the wall skin friction and heat transfer to the walls. The characteristics are obtained for a constant mass flow rate (0.3 Kg/s) of plasma in the duct. At the inlet of the MHD duct, the stagnation temperature of the plasma is assumed to be equal to the stagnation temperature at the combustor. The pressure at the duct exit is determined from the exit stagnation pressure of the diffuser with the assumed diffuser efficiency of 0.7. The electrical loading of the generator is taken into account by computing the current density J from the specified current or the voltage of an electrode pair [37]. The equations described in last section are solved by a two step time marching, finite difference Mac-Cormack algorithm which can handle subsonic, supersonic and transonic flows [73,84].

5.5.1 **Data for the calculation of electrical characteristics**

The specification for the simulation procedure are as follows:

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Duct: Linearly diverging from 3.2 cms to 4.2 cms in width
Length = 1 meter

Nozzle: Width = 3.3 cms to 3.2 cms
Length = 0.1 meter

Diffuser: Width = 4.2 cms
Length = 0.4 meter

The height of nozzle, duct and diffuser is constant at 0.1 meter.

Magnetic field: 3 Tesla
Diffuser Efficiency: 0.7
Electrode voltage drop: 40 volts
Electrodes: 20 pairs, pitch = 5 cm
Fuel: Coal seeded with KOH
Inlet temperature: 2800°K
Exit stagnation pressure: $1.1 \times 10^5$ pa
Mass flow rate: 0.3 Kg/s
Loading Parameter: varied between open circuit and short circuit

Finite difference increments

$$\Delta x = \frac{Z}{N-1} = 5\text{ cms}$$

$$\Delta t = \frac{0.6 \Delta x}{|u_{max}| + C_{max}}$$
\(\Delta t\) was set so as to obey the courant condition for the numerical stability of the Lax-Wendroff algorithm. The terms \(u_{\text{max}}\) and \(c_{\text{max}}\) are the values of the maximum gas velocity and maximum sonic velocity in the duct at any time.

With the above data the modified computer programme \[83\] was used to calculate the V-I characteristics of the generator. Figure 5.2 shows the V-I curves of the MHD generator for Faraday and diagonal mode. The programme MHD\(_4\) and sample output are listed in list D-1, table D-2 and D-3 in appendix D. The programme takes into account cross sectional area at \(N\) points when the duct is divided into \((N-1)\) equal subsection of width \(\Delta x\). The initial distribution of fluid state is specified for each point \(i\Delta x\) with \(i\) ranging from 2 to \(N\). The gas used for the simulation of real gas magnetohydrodynamic generator flows consists of the products of the combustion of coal with a stoichiometric amount of oxygen, equal amount of nitrogen and 1.5 percent by weight of potassium hydroxide (KOH) which is used as seed material. The coal data is calculated by a subroutine incorporated in programme MHD\(_4\). Rankin \[85\] has given the constants obtained from curve fits for the various equilibrium gas properties which were developed from the theory of an ideal gas and Saha's equation. These constants allow various properties of the gas to be calculated from the temperature and pressure. These constants are given in table D-4 of the appendix D.
FIG 5.2 V-I CURVES OF MHD GENERATOR
5.6 **Control of power to a.c. system**

The V-I curves shown in figure 5.2 are linear except for the end electrodes where there is sharp change in slope of the curve due to change in velocity from subsonic to supersonic. For the reference power the operating point chosen is same as discussed in chapter two. The 10th electrode V-I curves for the Faraday mode are taken for the analysis. The base quantities are chosen as discussed in section 2.2.3 of chapter two. The computer programme PHSPLT7 shown in table A-1 is incorporated with the programme MHD₄ for the control of power to a.c. system. The mass flow rate is varied to get variation in duct voltage and resistance. Power control due to change in voltage is shown in figure 5.3. Similar programme was run for diagonal mode where linearised characteristics were used for power control. The change in duct voltage is only considered because resistance is also function of mass flow rate for fixed geometry of the MHD duct. Therefore for any change in duct voltage resistance automatically varies. The desired power is controlled within 10 percent of the voltage variation from the operating point which is less than the cases considered in section 2.6.6 and 3.3.6. This is because of the reason that in computer model of the MHD generator, the internal resistance is variable quantity with mass flow rate.
FIG. 5.3. VARIATION OF REAL POWER WITH PHASE SHIFT CONTROL.

POWER IN P.U.

P.U. CHANGE IN V₀

0.0
0.05
0.10
0.15

-0.10
-0.05
0.0

0.2 0.4 0.6 0.8 1.0
5.7 Transient response of the MHD generator-inverter link

The transient response of an MHD generator to load fluctuations is an important study, particularly with a force commutated inverter. This study will lead to better design of inverter and control systems. Also this gives idea as to whether fluctuations due to load will be damped or cause instabilities.

In this section the same duct is used for transient analysis as described in section 5.5.1. The generator model discussed in section 5.5 is linked with the force commutated inverter interface for the transient analysis of the system. The system is subjected to sudden load changes from operating point to near open circuit and short circuit. The results are obtained for space and time variations for voltage, current, temperature, pressure and Mach number.

5.7.1 Derivation of equations for transient analysis

The energy source is constrained by shunt capacitors to act as a good approximation to an ideal voltage source. A d.c. input filter is added to limit the inverter ripple injection to MHD channel and the influence of the channel's voltage ripple on the inverter [41,86]. Figure 5.4 shows the block diagram of the MHD generator-inverter link with d.c. input filter.
FIG. 5.4. BLOCK DIAGRAM OF MHD GENERATOR-INVERTER LINK.
Initially the generator is assumed under steady state working at operating point and giving reference power. The d.c. input filter ($C_{in}$) is fully charged. We can write the following equations under this condition.

$$I_g - I_d = I_c = 0 \quad (5.27)$$

where $I_g$ = generator current under steady state 
$I_d$ = inverter current 
$I_c$ = current through capacitor. The current through the capacitor ($C_{in}$) is zero because under steady state it is fully charged.

The differential equation may be written at $t = 0$

$$I_c = C_{in} \frac{dV_d}{dt} \quad (5.28)$$

using equation (5.27) we can express equation (5.28) in difference equation as

$$\Delta V_d = (I_g - I_d) \frac{\Delta t}{C_{in}} = 0 \quad (5.29)$$

At time $t^* = 0$ a sudden change in load occurs. This current is to be supplied by the capacitor $C_{in}$ as current $I_g$ from MHD duct cannot change instantaneously because of fluid dynamic coupling of all the electrodes. The capacitor will discharge instantly leading to change in current ($I_g$) from generator.
Fluid dynamic conditions in the MHD channel will change now and V-I characteristics of all the electrodes will change. Iterative procedure is followed to predict the transient behaviour of the generator-inverter link. The following equations are written for Jth electrode and nth iteration for computerised solution of the transients:

\[ i_{cj}^n = I_{gj}^n - I_{dj}^n \]  
\[ \Delta V_{dj}^n = \Delta t \cdot i_c^n / C_{in} \]  
\[ V_{dj}^{n+1} = V_{dj}^n + \Delta V_{dj}^n \]  
\[ I_{gj}^{n+1} = (V_{gj}^{n+1} - V_{dj}^{n+1}) / R_{gj} \]  
\[ K_j^{n+1} = f(I_{gj}^{n+1}) \]  
\[ i_{cj}^{n+1} = I_{gj}^{n+1} - I_{dj}^{n+1} \]  
\[ t^{n+1} = t^n + \Delta t \]  

\( K_j^{n+1} \) is the new load factor which is a function of current as shown in equation (5.34). The above equations are linked with programme MHD for the transient behaviour of the MHD generator.
The calculations are carried for step changes in load from operating point. The data needed for calculations is same as described in section 5.5.1.

5.7.2 Transient response due to step increase in load

The operating point is chosen for a load factor of 0.5. The load is suddenly increased. The transient response due to increase in load is recorded by the computer plotter as shown in figure 5.5. Three different electrode pairs are chosen for simplicity. The one near inlet, the other in the middle and the 3rd at the exit of the duct. Voltages and currents are plotted against time. The internal resistance is different for different electrodes as this depends upon the geometry of the duct and conductivity. For this geometry, the internal resistance reduces towards the out of the duct. Therefore rate of rise of current for different electrodes is different. The difference in the rate of rise of current is small because the variation in internal resistance of the electrodes is small. The rate of change of current gives rise to large rate of change of Lorentz force. The voltage oscillations die down in 3 to 4 milliseconds and electrode pair voltages attain steady state value i.e. the operating value. The variation of pressure, temperature and Mach number along the duct is also plotted at different time intervals. At \( t = 0 \), the distribution of pressure, temp. and Mach number is shown in
Fig. 5.5. Transient response to load change.
figure D-5 in appendix D. From the plots it can be seen that pressure is increasing slightly from inlet to outlet of the duct and temperature is decreasing from inlet to outlet of the duct. The Mach number is increasing from inlet to outlet but the flow remains subsonic (M < 1). Figures D-6 and D-7 in appendix D show the computer plots of temperature, pressure and Mach number at different time intervals. It is observed from the above figures that after the steady state is attained, the distribution of these parameters have the uniform gradient and flow remains still subsonic.

5.7.3 Transient response due to step decrease in load

In this section a step decrease in load is considered from operating point. The voltage and current variation is plotted against time as shown in figure 5.6. The time response is plotted for 4th, 11th and 18th electrode pairs. The current decrease is almost exponential which characterises the nature of the circuit as R-C. The voltage oscillations in this case is more due to less retarding force compared to step increase in load. The voltage oscillations are settled in little less time compared to previous case. The variation of temperature, pressure and Mach number is also plotted along the duct at different time intervals. Figures D-8 to D-10 in appendix D show the variation of temperature, pressure and Mach number at different time intervals. The distribution of
these parameters becomes uniform after the transient is over and flow remains subsonic.

5.7.4 Transient response due to short circuit

In this section the generator is suddenly loaded near to short circuit from operating point. The actual short circuit \((K = 0)\) is not considered because of the numerical instability of the programme developed. Therefore the inlet electrode is taken as working at 0.05 load factor. The transient response is calculated and time variations of voltage and current are shown in figure 5.7. The response is similar to that discussed in section 5.7.2. The currents rise exponentially and attain the steady state with the same rate as discussed in section 5.7.2. The voltage oscillations are more pronounced and take more time to settle down to steady state. The space variation of temperature, pressure and Mach number is also plotted at different time intervals as shown in figures D-11 to D-19 in appendix D. The variation in temperature and pressure is more in this case compared to step increase in load. The Mach number is reduced from inlet to outlet of the duct. The flow along the duct still remains subsonic.

5.7.5 Transient response due to open circuit

In this section the transients due to sudden change in
FIG. 5.7. TRANSIENT RESPONSE TO LOAD CHANGE.
load from operating point to open circuit are considered. The load factor increases from 0.5 to near unity. The current and voltage transients are plotted in figure 5.8. The currents of different electrode configuration decrease to zero but voltages rise exponentially and about 2 ms seconds latter become oscillatory. The flow inside the generator becomes unstable and voltage oscillations increase in magnitude and frequency both. This case is most interesting because with the decrease in velocity at any electrode from previous value, changes the direction of current flow to electrode. The d.c. input filter has more charged voltage than the particular electrode pair when the velocity is decreased. Now the current is supplied from the filter to the generator electrode pairs, giving rise to negative retarding Lorentz force \( \mathbf{J} \times \mathbf{B} \). The fluid flow pattern is completely disturbed giving rise to instability inside the duct. The capacitor works as a source and sink both in open circuit case. The fluid velocity changes from subsonic to transonic. Therefore the capacitor should be disconnected in case of sudden open circuits. Figures D-14 to D-17 in appendix D, show the space variation of temperature, pressure and Mach number. More pronounced variation, are observed in temperature and pressure along the duct and about 7 ms, the flow pattern changes from subsonic to transonic as shown in figure D-16.
Fig. 5.8. Transient response to load change.
5.7.6 Transient response due to d.c. input filter

The size of the d.c. input filter is an important consideration for the determination of transient behaviour of the MHD generator. This acts as source when the electrode pair voltage is less than capacitor voltage \( V_d \) and sink when the electrode pair voltage is more than the capacitor voltage. For large size of capacitor, the Lorentz force \( J_y x B \) is more and for small size of the capacitor, the control action will be slow. Therefore the size of the capacitor was varied for the calculation of the transient behaviour. An optimum size of 0.1 \( \mu \text{F/VA} \) is suggested for better performance of the generator under transient conditions.

5.8 Summary and conclusion

In this chapter a time dependent computer model is considered for the calculation of electrical characteristics. These characteristics are used for the power control to a.c. system in different modes of loading of the MHD generator. A voltage source inverter (VSI) interface is taken for the transient analysis of the MHD-generator inverter link. A set of current and voltage equations are derived for the system. Digital simulation is carried out with these equations.

The duct is subjected to sudden load changes from operating point chosen for various cases. The computer plots
have been obtained for transients in voltage and current for the cases considered. The variation of temperature, pressure and Mach number along the duct is also plotted for the transient conditions. An optimum size of the input filter capacitor is also suggested for the better performance of the control system under transient conditions.