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Unit No: 1 Dynamics of Electric Drive

Q.1. Explain the block diagram & electric drive & the function of power modulator

Electric drive : Systems employed for motion control are called drives & may employ any of the prime movers such as, diesel or petrol engine, gas or steam turbine, steam engines, hydraulic motors & electric motors, for supplying mechanical energy for motion control. Drives employing electric motors are known as electrical drives.

The following are the block diagram of electric drive.

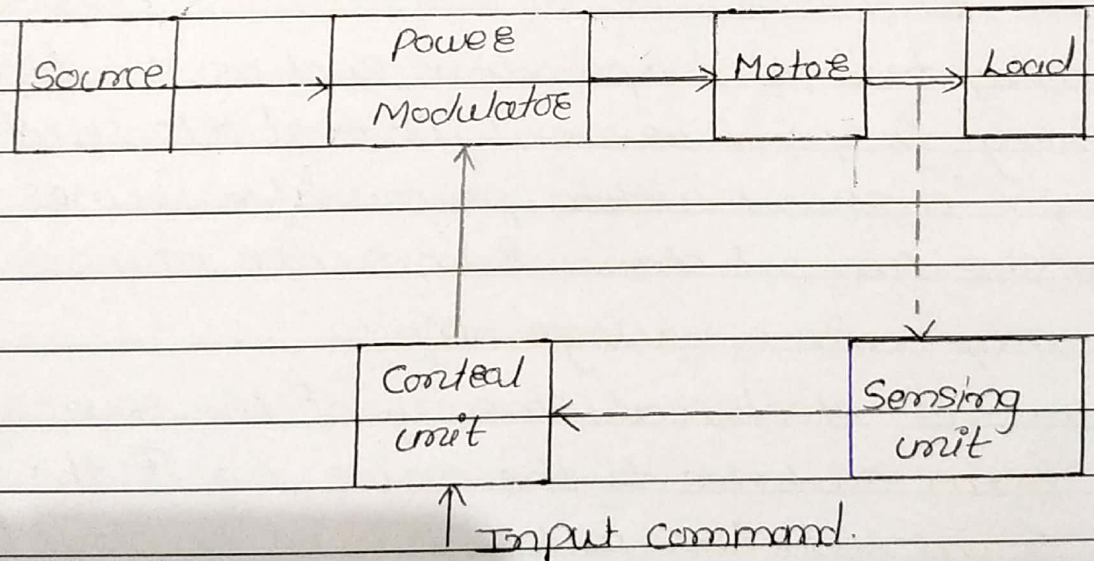

Fig 1 · Electric Drive

Block diagram of an electrical drive is shown in fig. 1, Load is usually a machinery designed to accomplish a given task, eg. fans, pumps, robts washing machines, machine tools, trains & drills. Usually load requirements can be specified in terms of speed & torque demands. A motor having speed-torque characteristics & capabilities compatible to the load requirements is chosen.

power modulator performs one or more of the following four functions.

i) modulates flow of power from the source to the motor in which such a manner that motor is imported speed-torque charactenistics required by the load.

ii) During transient operations, such as starting braking & speed reversal, it restricts source & motor current within permissible values; excessive current drawn from source may overload it or may cause a voltage dip.

iii) converts electrical energy of the source in the form suitable to the motor, e.g. if the source is dc & an induction motor is to be employed, then the power modulator is required to convert dc into a variable frequency dc

iv) Selects the modes of ~~mo~~ operation of the motor i.e motoring & braking

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When power modulator is employed mainly to perform function iii), it is more appropriately called converter. while iii) is the main function, depending on its circuit, a converter may perform other function of power modulator

Control for power modulator are built in control unit which usually operates at much lower voltage & power levels. In addition to operating the power modulator as desired, it may also generate commands for the protection of power modulator & motor. Input command signal, which adjust the operating point of the drive, forms an input to the control unit. sensing of certain drive parameter such as motor current & speed, may be required either for protection or for closed loop operation.

Q2. write short note on Dynamic conditions of a Drive system

when an electric motor rotates, it is usually connected to a load which has a rotational or translational motion. The speed of the motor may be different from that of the load. To analyze the relation among the drives & loads, the concept of dynamics of electrical drives is introduced

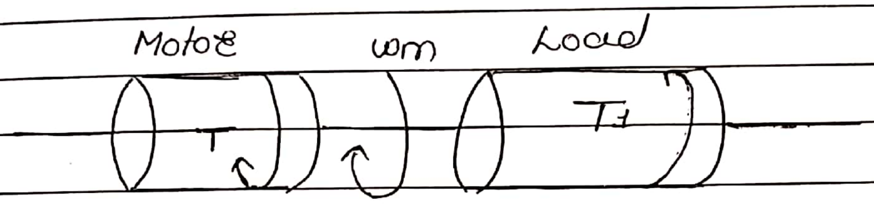

fig. motor load system

we can describe the dynamics of electrical drive easily by following instant.

Here,

J = polar moment of inertia of motor load

ω_m = Instantaneous angular velocity

T = Instantaneous value of developed motor torque

T_l = Instantaneous value of load torque referred to motor shaft.

Now from fundamental torque equation,

$$T - T_l = \frac{d}{dt}(J\omega_m) = J\frac{d\omega_m}{dt} + \omega_m\frac{dJ}{dt}$$

for drives with constant inertia,

$$\frac{dJ}{dt} = 0$$

Therefore, $T = T_l + J\frac{d\omega_m}{dt}$

So, the above equation states that the motor torque is balanced by load torque & a dynamic torque $J\left(\frac{d\omega_m}{dt}\right)$. This torque as it is only present during the transient operations.

From this equation, we can determine whether the drive is accelerating or decelerating such as during accelerating motor supplies load torque & additional torque component essentially. so the torque, balancing the dynamic of electrical braking is very helpful.

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Q.3 Explain what is meant by stedy state operation of a drive. List the factors affecting the stability of drive

Equilibrium speed of a motor-load system is obtained when motor torque equals the load torque. Drive will operate in Stedy-state at this speed, provided it is the speed of stable equilibrium. concept of stedy state stability of Drive has been developed to readily evaluate the stability of an equilibrium point from steady-state speed-torque curves of the motor & load, thus avoiding solution of differential equations valid for transient operation of the drive

In most drive, the electrical time constant of the motor is negligible compared to it's mechanical time constant. Therefore, during transient operation, motor can be assumed to be in electrical equilibrium implying that Steady-state speed-torque curves are also applic-able to the transient operation.

As an example let us examine the steady state stability of Drive of equilibrium point A in fig 2). The equilibrium point will be termed as stable when the operation will be restored to it after a small departure from it due to disturbance causes a reduction of $\Delta\omega_m$ in speed. At new speed, motor torque is greater than load torque, consequently, motor will accelerate & operation will restored to A.

Similarly an increase of $\Delta\omega_m$ in speed caused by a disturbance will make load torque greater than the motor torque, resulting into deceleration & restoration of operation to point A. Hence the drive is steady-state stable at point A.

Let us now examine equilibrium point B which is obtained when the same motor drives another load. A decrease in speed causes the load torque to become greater than the motor torque. drive accelerates & operating points moves away from B. Similarly, when working at B an increase in speed will make motor torque greater than the load torque, which will move operating points of equilibrium. Readers may similarly examine the steady state stability of drive of points C & D given in fig 2 (c) & (d)

Above discussion suggest that an equilibrium point will be stable when an increase in speed causes load-torque to exceed the motor torque.

i.e when at equilibrium point following condition is satisfied

$$\frac{dT_l}{d\omega_m} > \frac{dT}{d\omega_m} \quad \text{— i)}$$

inequality eqⁿ ① can be derived by an alternative approach. Let a small perturbation in speed $\Delta\omega_m$ results in ΔT & ΔT_l perturbations in T & T_l respectively. Then

$$(T+\Delta T) = (T_l+\Delta T_l) + J\frac{d(\omega_m+\Delta\omega_m)}{dt}$$

$$T+\Delta T = T_l + \Delta T_l + J\frac{d\omega_m}{dt} + J\frac{d\Delta\omega_m}{dt} \quad \text{— ii)}$$

substracting from 2) & rearranging terms gives.

$$J\frac{d\Delta\omega_m}{dt} = \Delta T - \Delta T_l \quad \text{— iii)}$$

for small perturbations, the speed torque curve of the motor & load can be assumed to be straight line.

$$\Delta T = \left(\frac{dT}{d\omega_m}\right)\Delta\omega_m \quad \text{— iv)}$$

$$\Delta T_l = \left(\frac{dT_l}{d\omega_m}\right)\Delta\omega_m \quad \text{— v)}$$

where $\left(\frac{dT}{d\omega_m}\right)$ & $\left(\frac{dT_l}{d\omega_m}\right)$ are respectively slopes of the steady state speed torque curves of motor & load at operating point under consideration. substituting eqn iv) & v) from iii) & rearranging the term yields

$$J \frac{d\Delta\omega m}{dt} + \left(\frac{dT_L}{d\omega m} - \frac{dT}{d\omega m}\right)\Delta\omega m = 0 \quad \text{(vi)}$$

This is a first order linear differential equatn if initial deviation in speed at $t=0$ be $(\Delta\omega m)_0$ then solution of eqn vi) will be

$$\Delta\omega m = (\Delta\omega m)_0 \exp\left\{-\frac{1}{J}\left(\frac{dT_L}{d\omega m} - \frac{dT}{d\omega m}\right)t\right\} \quad \text{vii)}$$

An operating point will be stable when $\Delta\omega m$ approaches zero as t approaches infinity for this to happen the exponent in eqn vii) must be negative. This yield the inequality of eqn iii).

Q. write short note on four quadrant operations of electric drive.

Ans: for consideration of multi quadrant of drive, it is useful to establish suitable conventions about the signs of torque & speed. A motor operate in two modes- motoring & Braking.

In motoring, it converts electrical energy into mechanical energy, which supports it's motion, in breaking it works as a generate converting mechanical energy into electrical energy & thus opposes the motion.

motor can provible motoring & breaking operation for both forward & reverse direction. fig. shows the torque & speed co-ordinates for both forward & reverse motion. power developed by a motor is given by the product of speed & torque for motoring operations. power developed is positive & for braking operation power developed is negative

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In quadrant I, developed power is positive, hence machine works, as a motor supplying mechanical energy, operation in quadrant I is therefore called forward Motoring.

In quadrant II, power developed is negative Hence, machin. works under braking opposing the motion. Therefore operation in quadrant II is known as forward braking.

similarly operation in quadrant III & IV can be identified as reverse motoring & reverse braking since speed in these quadrants is negative for better understanding of the above notation. Let us consider operation of hoist in four quadrant as shown in fig. 3).

A hoist consist of a torque wound on a drum coupled to the motor shaft one end of rope is tied to a cage which is used to transport man or material from one level to another level. other hand of rope has counter weight. weight of the counter weight is chosen to be higher than the weight of empty cage but lower than of a fully loaded cage. Forward direction of motor speed will be one which gives upward motion of the cage. Load torque line in quadrant I & IV represent speed-torque characteristics of the loaded hoist. This torque is the differentce of torque due to loaded hoist & counter weight.

The load torque in quadrant II & III is the speed torque characteristics for an empty hoist. This torque is the difference of torque due to counter weight & the empty hoist. its sign is negative because the counter is always higher than that of an empty cage. The quadrant I operation of a hoist requires movement of cage upward, which corresponds to the positive motor speed which is in counter clockwise direction here. This motion will be obtained if the motor product positive torque in CCW direction equal to the magnitude of load torque T_{L1}.

Since developed power is positive, this is forward motoring operation.

Quadrant IV is obtained when a loaded cage is lowered. since the weight of the loaded cage is higher than that of the canter weight, it is also able to overcome due to gravity itself.

In order to limit the cage within safe value motor must product a positive torque T equal to TL_2 in anticlockwise direction. As both power & speed are negative drive is operating in reverse braking operation. operation in quadrant II is obtained when an empty cage is moved up. since the canter weight is heavier than an empty cage. it's able to pull it up. in order to limit the speed within safe value, motor must produce a Braking torque equal to TL_2 in clockwise direction. Since speed is positive & development power is negative; it's forward braking operation

operation of III quadrant is obtained when an empty cage is lowerd, since an empty cage has a lesser weigh than a canter weigh, the motor should produce a torque in CW direction since speed is negative & developed power is positive, this is reverse motoring operation.

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Q.5. A drive has following parameters $T = 150 - 0.1N$, N - where N is speed in rpm. Load Torque $T = 100$ N-m. initially the drive is operating in stedy state. The characteristics of load torque are change to $T = -100$ N-m. calculate the initial & final equilibrium speed.

Solution: given data.

$T = 150 - 0.1N$, N-m

initial load torque $T_{l_1} = 100$ N-m

final load torque $T_{l_2} = -100$ N-m.

i) for initial equilibrium speed

$T = T_{l_1}$

$\therefore 150 - 0.1N = 100$

$0.1N = 150 - 100$

$0.1N = 50$

$N = 500$ rpm

$\therefore$ initial equilibrium speed is $N = 500$ rpm

ii) for final equilibrium speed,

$T = T_{l_2}$

$150 - 0.1N = -100$

$0.1N = 150 + 100$

$0.1N = 250$

$N = 2500$ rpm

final equilibrium speed is $N = 2500$ rpm.

Q.6 A drive has following equation for motor & load.

$$T = (1+\omega m) \quad \& \quad T_L = 3\sqrt{\omega m}$$

obtain the equilibrium point & determine their steady state stability. (W-17/6M)

Solution :

Given, motor Torque $= T = 1 + \omega m$

Load Torque $T_L = 3\sqrt{\omega m}$

At the equilibrium point

$$T = T_L$$

$$(1+\omega m) = 3\sqrt{\omega m}$$

i,e $(1+\omega m)^2 = (3\sqrt{\omega m})^2$

$$\therefore 1 + 2\omega m + \omega m^2 = 9\omega m$$

or $\omega m^2 - 7\omega m + 1 = 0 \quad \text{--- i)}$

Solving we eqn i) we get

$$\omega m = 6.854, \ 0.145$$

Thus the equilibrium points are

$T = 7.854$, $\omega m = 6.85$.

& $T = 1.145$, $\omega m = 0.145$

Also, $\frac{dT}{d\omega m} = 1$ & $\frac{dT_L}{d\omega m} = \frac{3}{2\sqrt{\omega m}}$

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At, $\omega m = 6.854$

$\frac{dT}{d\omega m} = 1$ & $\frac{dT_L}{d\omega m} = 0.573$

since

$\frac{dT_L}{d\omega m} < \frac{dT}{d\omega m}$, this equilibrium point is unstable.

At $\omega m = 0.145$

$\frac{dT}{d\omega m} = 1$ & $\frac{dT_L}{d\omega m} = 3.94$

So,

since

$\frac{dT_L}{d\omega m} > \frac{dT}{d\omega m}$

This is stable equilibrium point.

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Q.7. A drive has the following equation for motor & load torque. $T_m = (-1-2\omega_m)$ & $T_l = -4\sqrt{\omega_m}$ obtained the equilibrium points & determine their stedy state stability. (S-16/7M)

Solutions: motor torque $T_m = -1-2\omega_m$

Load torque $T_l = -4\sqrt{\omega_m}$

we know, At equilibrium,

$$T_m = T_l$$

$$-1-2\omega_m = -4\sqrt{\omega_m}$$

Squaring on both side.

$$1+4\omega_m+4\omega_m^2 = 16\,\omega_m$$

$$4\omega_m^2 - 12\omega_m + 1 = 0$$

So obtained,

$$\omega_m = 2.914,\ 0.086$$

Now.

$\omega_m = 2.914$ rad/sec

$\therefore T = (-1-2\omega_m)$

$T = (-1-2\times2.914) = -6.828$ N-m.

$\omega_m = 0.086$

$T = (-1-2\omega_m)$

$= (-1-2\times0.086) = -1.172$ N-m.

This two are equilibrium points

Now

$\frac{dT}{d\omega m} = \frac{d(-1-2\omega m)}{d\omega m}$ & $\frac{dT_l}{d\omega m} = -4\sqrt{\omega m}$

$\frac{dT}{d\omega m} = -2$

$= \frac{d}{d\omega m}(-4\sqrt{\omega m})$

$= -\frac{2}{\sqrt{\omega m}}$

For $\omega m = 2.914$ rad/sec

$\frac{dT}{d\omega m} = -2$ & $\frac{dT_L}{d\omega m} = -1.1716$

Since $\frac{dT_l}{d\omega m} > \frac{dT_l}{d\omega m}$, This operating point is stable.

for $\omega m = 0.086$

$\frac{dT}{d\omega m} = -2$ & $\frac{dT_L}{d\omega m} = -6.81$

Since, $\frac{dT_L}{d\omega m} < \frac{dT}{d\omega m}$

This operating point is unstable.

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Q.8. A motor is used to drive a hoist motor characteristics are given by
Quadrant I, II & IV : $T = 200 - 0.2N$, N-m
Quadrant II, III & IV : $T = -200 - 0.2N$, N-m
where hoist is load the net torque $T_l = 100$ N-m & when it is unloaded net torque $T_l = -80$ N-m obtained equilibrium speed for operation in all the four quadrants

(S-16, S-18 / 7M)

Solution :

1st quadrant operation

Hoist is loaded, hence $T_l = 100$ N-m

At equilibrium, $T = T_l$.

$$T = T_l$$
$$200 - 0.2N = 100$$
$$0.2N = 200 - 100$$
$$0.2N = 100$$
$$N = 500 \text{ rpm}$$

2nd quadrand operation

Hoist is unloaded, hence $T_l = -80$ N-m.

At equilibrium, $T = T_l$

$$200 - 0.2N = -80$$
$$0.2N = 280$$
$$N = 1400 \text{ rpm}$$

3rd quadrant operation

Hoist is unloaded, $T_l = -80$ NM

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At equilibrium

$T = T_L$

$-200 - 0.2N = -80\ N$

$0.2N = -120$

$N = -600$ rpm.

4th Quadrant operation.

Hoist is loaded, hence $T_L = 100$ N-m

At equilibrium

$T = T_L$

$-200 - 0.2N = 100$

$0.2N = -300$

$\therefore N = -1500$ rpm.

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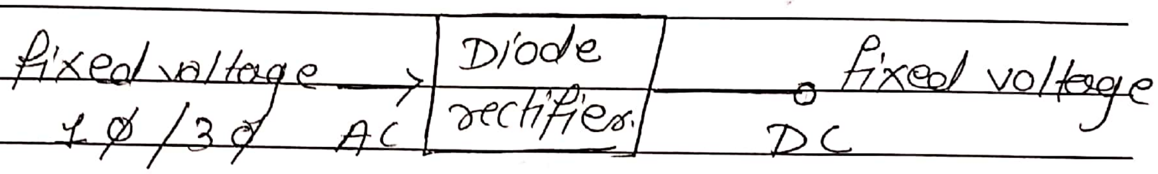
Q.9. State & explain the function of various converters (W-2016 / 7M)

Ans : The various converters are as follows.

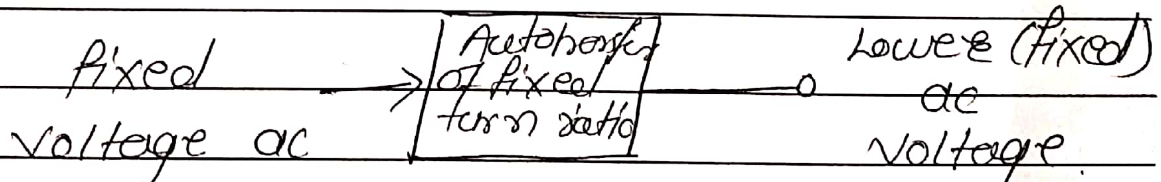
i) AC to dc converters : AC to DC converters are required when the supply is ac & a dc motor is to be controlled. These converter can convert fixed voltage ac supply to either fixed dc or variable dc dependending on requirement.

ex.



ii) ac voltage controller : AC Voltage controller are employed to get variable ac voltage of the same frequency from a source of fixed ac voltage.

examples



iii) chopper : They are used to get variable voltage dc from a fixed voltage dc & are designed using semiconductor device such as power transistor, IGBT'S, power MOSFETs etc.