Department of Electrical Engineering
Assignment
Date: 23/06/2020

Course Details

Course Title: Direct Energy Conversions **Module:** semester
Instructor: **Total Marks:** 50

Student Details

Name: IMTIAZ ALI **Student ID:** 14892

Note: Plagiarism of more than 20% will result in negative marking.
Similar answers of students will result in cancellation of the answer for all parties.

Q1.	(a)	Magneto hydrodynamics (MHD) is a direct energy conversion technique. What are the basic differences in working principle of this system as compared to conventional hydro power systems. How is the output power obtained from this system.	Marks 10
Q2.	(a)	Thermo-electric systems are emerging as a popular alternate to conventional thermal power systems. What are the main factors involved in the technology that determine the output power of thermos-electric generator. How can the maximum power be obtained from this system.	Marks 10
Q3.	(a)	The Thermionic generator has two main types (i) Vacuum Convertor and (ii) Cesium Gas Convertor. Explain in detail why which convertor is more efficient, has more life-time and is easier to construct/operate.	Marks 10
Q4	(a)	Thermo-electric and Thermionic are DEC techniques. What are the common principle in both systems. What are the main differences between both the systems. Explain in detail.	Marks 10
Q5	(a)	Thermo-Nuclear fusion has the potential to provide unlimited clean power. But the technology has not been mainstreamed due to technical difficulties. What are the main issues with the system. How can they be solved.	Marks 10

Question:01 (a)

Answer:

The magneto hydrodynamics (MHD) is a direct energy conversion system which converts the heat energy directly into electrical energy. Without any intermediate mechanical energy conversion, as opposed to the case in all other power generating plants. In advanced countries MHD generators are widely used but in developing countries, it is still under construction.

Principle of MHD Generation:

The principle of MHD power generation is based on faradays law of electromagnetic induction which states that when the conductor moves through a magnetic field, it generates an electric field perpendicular to the magnetic field & direction of conductor.

The induced EMF is given by

$E_{ind} = u \times B$

where u = velocity of the conductor.

B = magnetic field intensity.

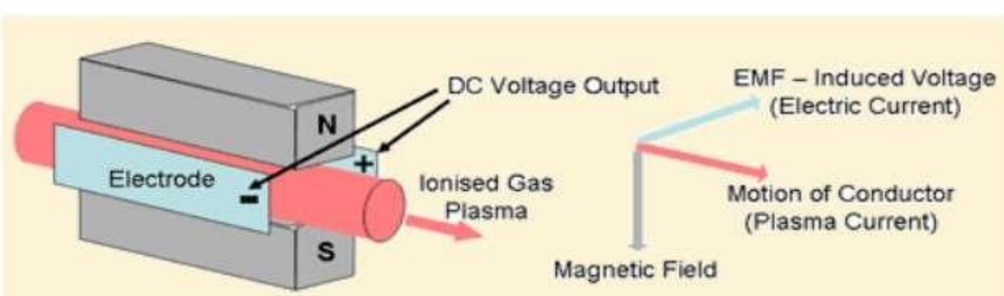
The induced current is given by,

$I_{ind} = C \times E_{ind}$ where C = electric conductivity

The retarding force on the conductor is the Lorentz force given by

$F_{ind} = I_{ind} \times B$

As the name implies the magneto hydro dynamics generator is concerned with the conducting fluid flow is forced between the plates with a kinetic energy and pressure differential sufficient to overcome the magnetic induction force. In conventional generator the conductor consist of copper windings in an MHD generator hot ionized gas replace s the solid conductor. A pressurized electrically conducting fluid flows through a transverse magnetic field in a channel or duct pair of electrodes are located on the channel walls at right angle to the magnetic field and connected through an external circuit to deliver power to a load connected to it. Electrodes in the MHD generator perform the same function as brushes in a conventional generator. The MHD generator develops DC power and the conversion to AC by using an inverter.



Magnetohydrodynamic Power Generation (Principle)

$\rho = \sigma B^2 v^2 K (1 - K)\ W/m^3$

Where σ is the specific electrical conductivity of gas in siemen/ metre,

B is magnetic field strength in Tesla (Wb/m^2),

v is the velocity of gas in m/s

K is the ratio of external load voltage to open-circuit voltage.

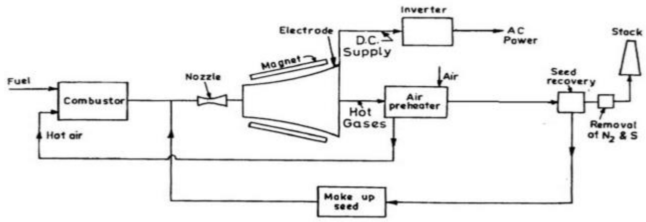
The MHD cycles have two types which are:

Open cycle MHD

Closed cycle MHD

Open cycle MHD system:

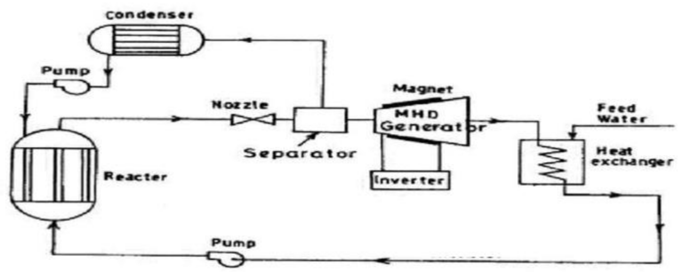
- The fuel used maybe oil through an oil tank or gasified coal through a coal gasification plant.
- The fuel (coal, oil or natural gas) is burnt in the combustor or combustion chamber.
- The hot gases from combustor is then seeded with a small amount of ionized alkali metal (cesium or potassium) to increase the electrical conductivity of the gas.
- The seed material, generally potassium carbonate is injected into the combustion chamber, the potassium is then ionized by the hot combustion gases at temperature of roughly 2300' c to 2700'c.
- To attain such high temperatures, the compressed air is used to burn the coal in the combustion chamber, must be adequate to at least 1100^0c.
- A lower preheat temperature would be adequate if the air is enriched in oxygen. An alternative is used to compress oxygen alone for combustion of fuel, little or no preheating is then required. The additional cost of oxygen might be balanced by saving on the preheater.
- The hot pressurized working fluid leaving the combustor flows through a convergent divergent nozzle. In passing through the nozzle, the random motion energy of the molecules in the hot gas is largely converted into directed, mass of energy. Thus, the gas emerges from the nozzle and enters the MHD generator unit at a high velocity.



Open cycle MHD System

Closed cycle MHD system:

As the name suggests the working fluid in close cycle MHD is circulated in a closed loop. Hence in this case inert gas or liquid metal is used as the working fluid to transfer the heat. The liquid metal has typically the advantage of high electrical conductivity hence the heat provided by the combustion material need not be to high. Contrary to the open loop system there is no inlet and outlet for the atmospheric air. Hence the process is simplified to a great extent as the same fluid is circulated time and again for effective heat transfer.



Closed cycle MHD generator using liquid metal as working fluid coupled with steam genarator.

Question:02 (a)

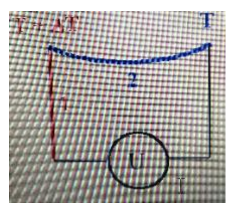
Answer:

Seebeck, Peltier and Thomson effect:

Seebeck effect:

When the junctions of two different metals are maintained at different temperature, the emf is produced in the circuit. This is known as Seebeck effect.

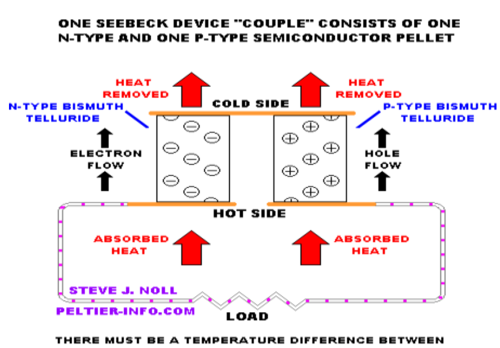
The conductor 1 is maintained at T+Δ**T** temperature



The conductor 2 is maintained at

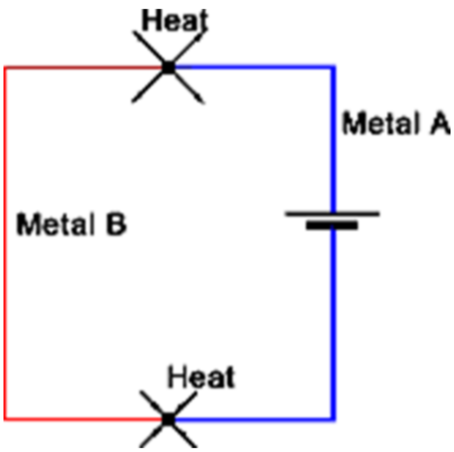
Temperature 'T'.

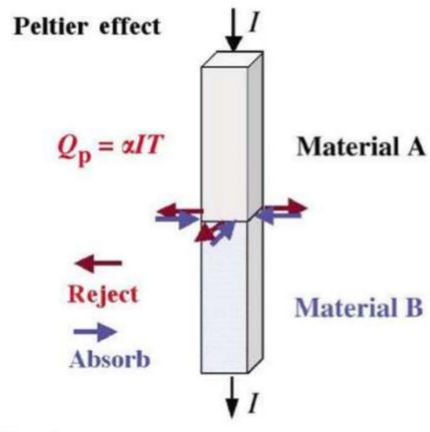
Since the junctions are maintained at different temperature, the emf 'U' flows across the circuit.

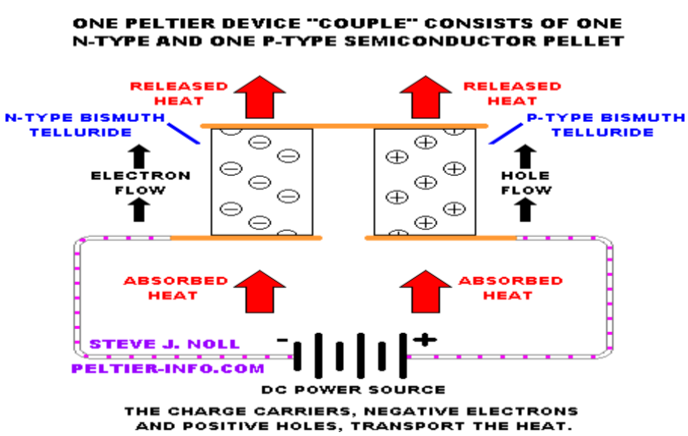


Peltier effect:

Whenever current passes through the circuit of two dissimilar conductors, depending on the current direction, either heat is absorbed or released at the junction of the two conductors. This is known as Peltier effect.







Joule effect:

Irreversible conversion of electrical energy into heat when a current I flows through a resistance R.

$Q_j = I^2R$

Thomson effect:

Heat is absorbed or produced when current flows in material with a certain temperature gradient. The heat is proportional to both the electric current and the temperature gradient. This is known as Thomson effect.

The maximum power can be obtained from the following:

1. Large Seebeck coefficients
2. High electrical conductivity
3. Low thermal conductivity

Question:03 (a)

Answer:

A thermionic converter consists of a hot electrode which thermionically emits electrode a potential energy barrier to a cooler electrode, producing a useful electric power output. The vapor is used to optimize the electrode work functions and provide an ion supply to neutralize electron space charge.

The two main types of Thermionic generator are:

- Vacuum close-spaced convertor
- Cesium Gas Filled convertor

Vacuum close-spaced convertor:

It has been under extensive research since 1957 and Physical spacing of .0005 inch or less is maintained between anode and cathode. Will have engineering difficulty and Lifetime is 40 hours

Cesium Gas Filled convertor:

- Cesium gas is filled between anode and cathode.
- Working efficiency is higher than former one.
- Lifetime is nearly 600 hours.
- Main problem is efficient sealing and corrosive nature of cesium.

Advantages:

1. Rotating equipment is not employed
2. Liquid-Vapour phase problems do not exist
3. Separators for fluids are not required

4. Frictional losses due to bearings not present

Disadvantages:

1. Individual convertors are low voltage, high current devices
2. A large number of convertors must be sequentially arranged to obtain useful voltage
3. Power losses in convertors can seriously cut useful power output

Cesium Gas Filled convertor is more efficient than Vacuum close-spaced convertor and cesium gas filled converter is more life time and easier to construct than Vacuum close-spaced convertor. The Vacuum close-spaced convertor life time is 40hr and Cesium Gas Filled convertor is 600hr.

Question:04 (a)

Answer:

The common principle of thermo- electric and thermionic are:

Thermoelectric:

Thermoelectric power generator based on the principle of **See beck effect** that when the junctions of two different metals are maintained at different temperature, the emf is produced in the circuit

- In order to select materials and design a thermoelectric generator, one needs to start with a general understanding of the thermoelectric effects.
- In a thermoelectric material there are free carriers which carry both charge and heat.
- Perhaps the simplest example is a gas of charged particles.
- If a gas is placed in a box within a temperature gradient, where one side is cold and the other is hot, the gas molecules at the hot end will move faster than those at the cold end.
- The faster hot molecules will diffuse further than the cold molecules and so there will be a net buildup of molecules (higher density) at the cold end.
- The density gradient will cause the molecules to diffuse back to the hot end.
- In the steady state, the effect of the density gradient will exactly counteract the effect of the temperature gradient so there is no net flow of molecules.
- If the molecules are charged, the buildup of charge at the cold end will also produce a repulsive electrostatic force (and therefore electric potential) to push the charges back to the hot end.

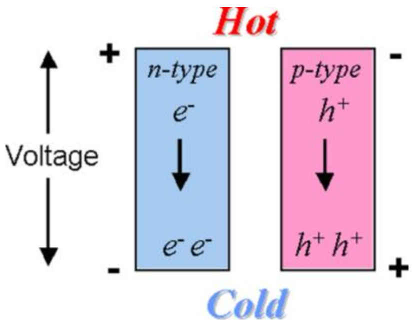


Diagram shows the charge buildup at cold side

- The electric potential produce by a temperature difference is known as the See beck effect and the proportionality constant is called See beck coefficient (α).
- If the free charges are positive (the material is p-type), positive charge If the free charges are positive (the material is p-type), have a positive potential.
- Similarly, negative free charges (n-type material) will produce a negative potential at the cold end.

Thermionic:

- A thermionic energy converter (or) thermionic power generator is a device consisting of two electrodes placed near one another in a vacuum.
- One electrode is normally called the cathode, or emitter, and the other is called the anode, or plate.
- Ordinarily, electrons in the cathode are prevented from escaping from the surface by a potential-energy barrier.
- When an electron starts to move away from the surface, it induces a corresponding positive charge in the material , which tends to pull it back into the surface.
- To escape, the electron must somehow acquire enough energy to overcome this energy barrier.
- At ordinary temperatures, almost none of the electrons can acquire enough energy to escape.
- However, when the cathode is very hot, the electron energies are greatly increased by thermal motion.
- At sufficiently high temperatures, a considerable number of electrons are able to escape.
- The liberation of electrons from a hot surface is called thermionic emission.

Depend on heat energy and transmitting electron at high temperature.

The main difference between thermionic and thermoelectric are:

- Both thermionic and thermoelectric generators employ the electron gas as the working fluid.
- A thermionic generator based on the ballistic current flow which is highly efficient, and its theoretical efficiency is close to the Carnot efficiency.
- A thermoelectric generator, however has poor efficiency due to the diffusive current flow.
- A thermionic generator usually requires a high temperature heat source e.g 1500 k to generate a practically useful current.
- A thermoelectric generator, however, can produce electrical power from low-quality heat energy sources.

Question:05 (a)

Answer:

The issues of Thermo- Nuclear fusion are:

- **Planned availability**
- **Reliability**
- **Structural integrity**
- **Helium supply**
- **High-temperature plasma-facing materials**
- **Problematic materials**

Planned availability:

Large capital costs with a small marginal cost of electricity-generation force fusion power towards base-load supply. D Ladra and co-workers have reported: "to be competitive, fusion power stations should have high availability, preferably exceeding 80%, with very few unplanned shutdowns".[30] The 80% target, now routinely achieved by fission technology, will be a stretch for any planned fusion power station. The requirement for continuous power at high availability is particularly demanding for the tokamak's essentially pulsed output, albeit possibly operating in very-long-pulse mode. Although researchers suggest that plasma motion and stability can be maintained for many hours after the initiating voltage sweep, there is a significant availability difference between long-pulse operations and a truly continuous operation. Much consideration has been given to the challenge of continuous operation.

Reliability:

An even greater challenge than availability is the need to achieve very high levels of reliability. That is, unscheduled and unanticipated interruptions to power generation must be avoided. A fusion-based electricity company in a modern competitive electricity market will need to enter into long-term bilateral contracts with electricity suppliers to provide the necessary business stability. A rule of thumb for plasma stability in tokamaks is: the bigger the machine, the better. Also, the engineering of a fusion power station is likely to face significant economies of scale, further favouring large machines of at least 1.5 GW electrical output. If such a machine were to be forced to shut down unexpectedly then there would be significant penalties in the electricity market.

Structural integrity:

As a consequence of its basis as a transformer driven by a single sweep of the primary, a tokamak is inherently a pulsed device. A power station will operate with very long pulses, but during its life it will still be subject to many tens of thousands of pulses. Given the very large magnetic fields associated with plasma confinement and drive, each pulse will place significant magnetic stresses on the structure of the power station. The station must withstand repeated cycling of these structural loads.

Much of a station's structure, such as the blanket, will be at high temperatures at which conventional steels cease to have good tensile properties, and this will make the structural strength of the machine an even greater challenge.

Lastly, some of the structural components could be exposed to significant neutron fluxes. Each fast neutron impact can cause microstructural defects in engineering materials.

Helium supply:

While the fuels for fusion power are abundant and easily obtained, this does not mean that a fusion power station would be free from energy security risks. Central to such risks must be the long-term availability of affordable helium used for tokamak pumping, purging and, above all, cooling superconducting magnets. While helium could in principle be obtained from the atmosphere at great cost, and while it is also possible that economically viable helium gas wells could be developed, the reality today is that all commercial helium is obtained as a by-product of the natural-gas industry. That industry is expanding and, as it moves towards liquefied production and supply, the economics of helium production are favored. While it is likely that abundant helium will be available in the short term, the natural gas industry is a fundamentally unsustainable process of resource depletion. These issues are considered by a joint UKAEA, Linde-BOC and University of Cambridge research project considering global helium resources.[32] Helium availability and cost are potentially serious issues for the large-scale deployment of fusion energy systems.

High-temperature plasma-facing materials :

The diverter Components directly facing the very hot fusion plasma include the first wall of the blanket on the outer edge of the torus and the diverter, which is usually placed round the bottom of the torus. In all MCF the plasma must at some point touch the vacuum vessel. This could be using a device dedicated to that purpose (a limiter), but more conventionally that role is played by the diverters. As a result of contact with the vacuum vessel, the tiles of the diverter will glow white hot. It is expected that these tiles will need frequent replacement and, given that the tokamak vessel will be a highly radioactive environment, this will need to be done robotically. At JET, much effort has gone into such remote handling. Nevertheless, diverter component reliability and replacement represent key challenges for a fusion power station.

Problematic materials:

It is often rightly stressed that, if properly developed, a fusion power programme need not lead to a legacy of long-lived radioactive waste. The waste of the fusion process is harmless helium gas in small quantities. The main issue of concern for waste is the radioactivation of the tokamak. It is possible to manufacture the device from materials known only to activate into short-lived radioisotopes. As such we can be confident that a fusion power station would leave a negligible radioactive legacy 100 years after shutdown.

A more controversial matter is whether fusion energy would represent a proliferation hazard. There is agreement on the benefits of fusion making no use of fissile isotopes such as uranium-235 or plutonium-239, which are required for fission weapons, but beyond that opinion is divided. The remaining issues fall into two broad classes: tritium and fast neutrons.