Electrical Machines

7.1 Introduction

Michael Faraday’s most outstanding discoveries in electro-magnetism during 1830s form the very early origins of transformers, alternators, and DC generators. He had a ring made of soft iron over which two copper coils were wound. Upon making and braking current through one of the coils, he observed disturbance of a magnetic needle placed near the second coil. This is considered as the first model of a transformer where interrelationship between electricity and magnetism was observed. In 1831, Faraday performed one more series of experiments in which he passed a coil wound on a hollow paper cylinder swiftly over a cylindrical bar magnet. Ends of the coil were connected to a galvanometer. The galvanometer pointer showed deflection as long as the coil was in motion. This was the first ‘alternator’ where a relative motion between magnet and conductor produced electricity. In the same year 1831, Faraday discovered a rotating machine that can be thought as the origin of DC generator. He had a revolving copper disc placed in the small gap between a pair of magnetic poles. To make contact with the revolving plate he amalgamated two metal brushes with mercury, one at the end of the disc and the other on the axle. The two brushes were connected to a galvanometer. The galvanometer showed steady deflection, indicating production of direct current as long as the disc was revolved.

Faraday’s achievements in 1831 led to the development of practical electric machines – dynamos, alternators, and motors that could convert mechanical energy to electrical energy interchangeably in both ways.

In fact, the idea of interaction of electric and magnetic fields as demonstrated by Hans Christian Oersted and André-Marie Ampère back in the 1820s, was the basis for development of motors and generators in the years to follow. For over more than 100 years, eminent scientists, physicists and engineers whose long list contain names like Peter Barlow (1822), François Arago (1824), Joseph Henry (1831), William Sturgeon (1833), Joseph Saxton (1833), Thomas Davenport (1837), Werner Siemens (1856), Walter Baily (1879), Galileo Ferraris (1885), Nikola Tesla (1889), Mikhail Dolivo Dobrovolskyn (1890) and many more contributed to development of the motors and generators that we see today.

7.2 Electromechanical energy conversion

Different components of a typical electromechanical energy conversion system and their interrelationships are pictorially shown in Fig 2.1. As illustrated in Fig 2.1, an electromechanical system consists of the following three basic components:

- An electrical subsystem (electric circuits such as windings)
- A magnetic subsystem (magnetic field in the magnetic cores and air gap)
- A mechanical subsystem (mechanically movable parts such as a plunger in a linear actuator or s rotor in a rotating electrical machine)

Voltages and currents are used to describe performance of the electrical subsystem and they are governed by the basic circuital laws, namely: Ohm's law, KCL and KVL. State of the mechanical subsystem can be described in terms of torque and speed, and is governed by the Newton's laws. The magnetic subsystem or magnetic field that acts as a ***coupling*** between the electrical and mechanical subsystems is described by quantities such as magnetic flux, flux density, and field strength. These are governed by the Maxwell's equations.

When coupled with an electric circuit, the magnetic flux interacting with the current in the circuit would produce a force or torque on a mechanically movable part. On the other hand, the movements of the moving part will could variation of the magnetic flux linking the electric circuit and induce an electromotive force (emf) in the circuit.

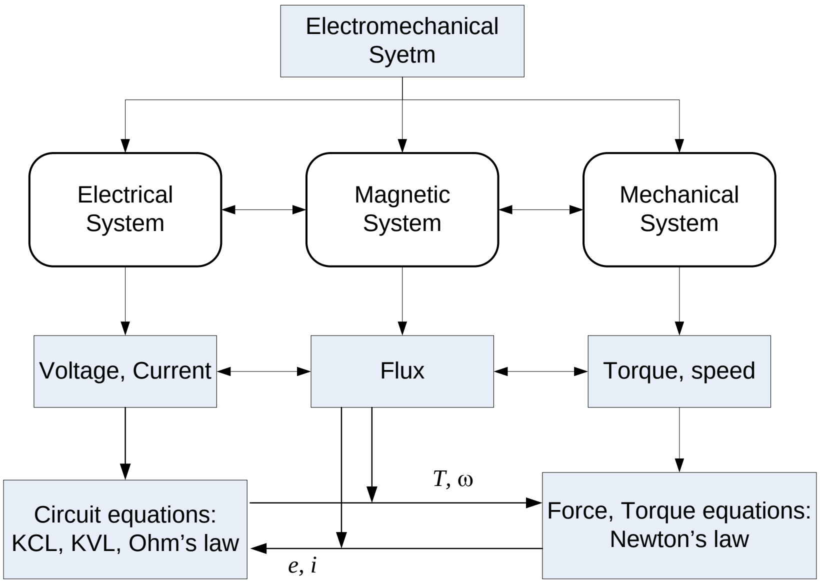

Fig. 2.1 Mapping of electromechanical energy conversion components

Basic operating principle of all rotating electrical machines is based on conversion of electrical energy to mechanical energy and vice versa. This conversion of one form of energy to the other form generally takes place through a coupling medium, either a magnetic field or an electric field. In a conventional motor electrical energy is drawn from the supply which is converted first to magnetic energy in the coupling medium, and then converted back to mechanical energy in the rotating part of the machine to drive mechanical loads such as line shafts or machine tools. On the other hand, when the machine is driven mechanically by a prime mover such as engine, or turbine, the mechanical energy is transmitted through a magnetic field to be converted to electrical energy from the generator output terminals. The electromechanical energy conversion process is reversible, except for the losses in the system that may take place during the conversion process. The term "reversible" implies that the energy can be transferred back and forth between the electrical and the mechanical systems.