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Introductory Chapter: Electric Power Conversion

Marian Găiceanu

1. Chapter overview

The introductory chapter has in view an incursion in discovering electricity, how can be handled, and the future of it. The chapter starts with the ancient discovery of electricity. Starting from the Kite experiment to the energy use of lightning is mentioned in the *New Discoveries in the Electricity* section. Moreover, the current path from the electrostatic machine to ion wind propulsion system is mentioned in the same section. A short history of energy conversion technology is described in the forthcoming section. Different electric power conversion technologies are mentioned. The possible pathways of the future electric power conversion are mentioned. Some ideas about electric power conversion development are mentioned at the end of this chapter.

2. The ancient discovery of the electricity

Electricity is a natural phenomenon. One of the first known discovered natural electricity generations is the *electric fish* (discovered in twenty eighth century BC by the Egyptian). These types of fish are named *electrogenic* (one of the most dangerous fish is the *electric eel*—*electrophorus electricus*—due to the lethal electric shocks generation), being capable to generate the electric fields through electric organ discharge (EOD). Nowadays, the *bioelectrogenesis* (generation of the electricity by the living organisms) phenomenon is studied by the *electrophysiology* science branch. The receiver fish of the electric field is named *electroreceptive*, having the ability to receive the electric field through the *electroreception* feature [1].

The Thales of Miletus (around 600 BC) remarked the attraction of lightweight material by rubbed amber (ἤλεκτρον in Greeks or *ēlektron*), discovering static electricity [2]. However, as the archeological discoveries are on-going the researchers make hypothesis of electric light existence in ancient Egypt [3–6].

3. New discoveries in the electricity

In 1600 the scientist William Gilbert published the on the *Magnet treatise*, becoming the *Father of Electricity* [7]. In his published work *Pseudodoxia Epidemica* (1646), second book—*Tenets Concerning Mineral and Vegetable Bodies*, Thomas

Browne used the word *Electricity*. The inventor of the *Electricity* (1663) was declared Otto von Guericke by producing static electricity by friction of a sulfur ball [8].

The first discover of conductors and insulators were made by the Stephen Gray (1731). Charles François de Cisternay du Fay discovered the existence of two electricity types: vitreous and resinous (1733), which were renamed positive and negative electricity by Benjamin Franklin in 1750.

Through the bolt of lightning Benjamin Franklin discovers the connection between lightning and electricity, as observed in the *Kite Experiment* (1752) [9].

The bolt of lightning can be intra-cloud (**Figure 1a**), between clouds (**Figure 1b**) or between cloud and ground (**Figure 1c**) [10].

A massive steel sculpture was performed by Isamu Noguchi in Philadelphia [11], as a memorial to Benjamin Franklin (**Figure 1d**) [12].

An average value of the energy released during thunderstorm is about 10,000,000 kilowatt-hours (3.6×10^{13} joule) [13].

Taking into account such huge quantity of energy provided in a very short time, the scientists propose the use of the captured lightning energy as alternative energy in different kinds of patents [14, 15] in order to use the stored energy lately.

In the future, as the nanotechnology penetrates the scientific knowledge environment the lightning energy could be a real alternative energy solution.

In 1741 William Watson used a vacuum glow-lamp supplied by an electrostatic machine.

Recently, at the end of 2018 the MIT engineers have been discovered the first no moving parts aircraft by using the electrostatic energy (**Figure 2**) [16]. They used the electro aerodynamic thrust principle to design ion wind propulsion system.

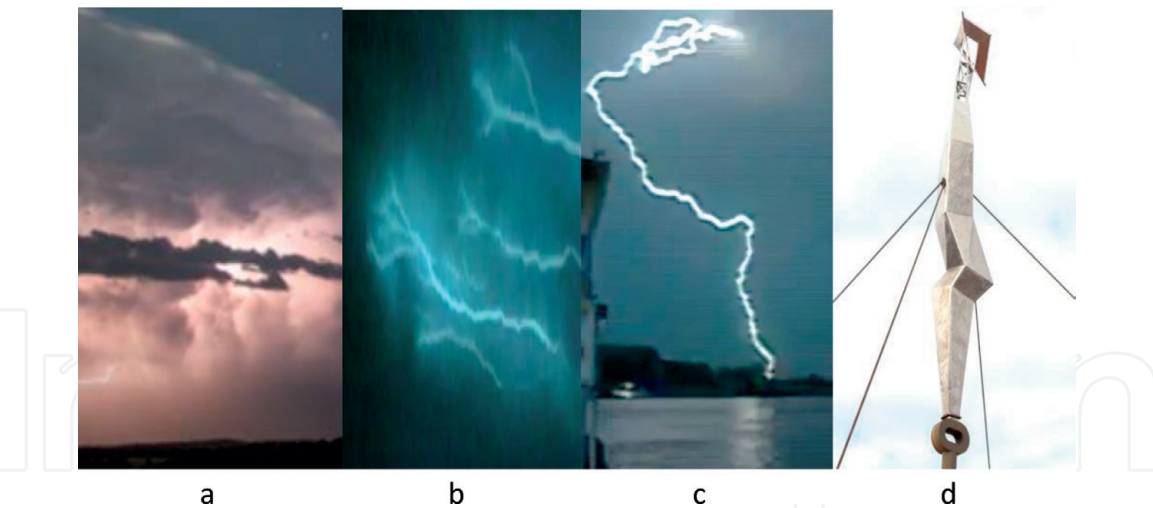


Figure 1.
The bolt of lightning (a) intracloud (b) between vertical clouds (c) between cloud and ground (d) bolt of lightning.

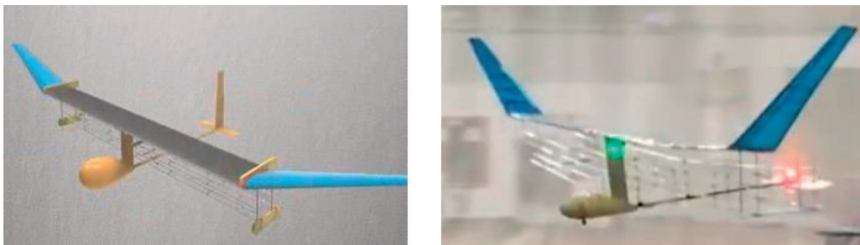


Figure 2.
The first no moving parts aircraft by using the electrostatic energy [17].

The bioelectricity was discovered by Luigi Galvani in 1780. The voltaic pile was made in 1800 by Alessandro Volta (the international unit for electric potential difference—voltage—is volt). This invention was a huge step regarding the source of the electricity, being more reliable than the electrostatic generator.

The actual technologies in electrical energy storage could be reviewed in [18].

The NAWA Technologies introduced in mass production the new technology as ultra fast carbon battery which is carbon-based ultracapacitor with vertically aligned carbon nanotube (VACNT) [19].

The future of the energy storage could be graphene-based supercapacitors. This new type delivers four times more energy density than the current supercapacitors, maintaining high power and long operational life (Meilin Liu) [20]. In 1802, Humphry Davy invented the incandescent lamp.

4. A short history of energy conversion technology

The energy conversion technology starts with biomass (primarily wood: dried plants) conversion to heat. The mechanical energy was obtained to replace the animal or human power. In order to obtain the mechanical energy as primary energy sources wind (air flowing by using windmills) or flowing water (by using water-wheels) were used. The first notes of windmills were from Hero of Alexandria, in the first century of common era (CE). The ocean tides were the primary source of energy for tidal mills since 1086. The idea of conversion steam power to move a piston into cylinder (earlier pump) was delivered by Denis Papin (1679). The conversion of the thermal energy (steam) into hydraulic energy was patented by Thomas Savery (1698). Thomas Newcome, together with Savery invented the first piston-operated steam pump (1712). James Watt was the Father of the Watt steam engine (1765), a modern way of the steam engine.

The first steam powered locomotive was provided by Richard Trevithick (1803) [21]. Robert Stirling patented in 1816 the engine without high-pressure boiler (for safety reason). The mechanical energy conversion into electricity was discovered by Michael Faraday by using electrical generator (1830s).

5. Energy conversion technologies

The total energy of one system, according to the first thermodynamics law, is composed by heat and capacity to do the work. The standard unit of energy is *joule* (after the name of scientist James Prescott Joule). The efficiency of the energy conversion is defined by the second law of thermodynamics [22]. The energy cannot be created or destroyed, only transformed it from one form to another (law of conservation of energy). In other words, the energy within a reference frame the energy is always the same.

The energy per unit time is power. The unit *watt* was introduced by Carl William Siemens (1882) for *real power* in AC system. The *watt* name is provided after the James Watt.

According to [23] (the *metric EU directive*), the symbol of the *reactive power* is “*var*” and it was proposed in 1929 by the Prof. Constantin Budeanu and introduced in 1930 by the International Electrotechnical Commission in Stockholm, as international unit for reactive power [24].

There are two main states of energy potential (store) and kinetic (in motion, working). There are several forms of energy: chemical, nuclear, gravitational, elastic (stored), electrical, electromagnetic (radiant, light), mechanical, thermal (heat), ionization, sound.

The energy conversion takes place through power converters. Power converters can be rotating (electromechanical) or static.

5.1 Electromechanical power converters

In 1821 Michael Faraday invented the electric motor (a primitive version).

The relationship between the current and the voltage, known as Ohm's law, was quantified by Georg Ohm in 1827. Four years later, in 1831 Michael Faraday discovered the electromagnetic induction and the electromechanical conversion of the energy. Through the experiments, Faraday demonstrated that the electricity is obtained by friction, electromagnetic induction, chemical or thermoelectric. Werner von Siemens demonstrated the obtaining of the electric light from dynamo generators (1867). Siemens laid the groundwork of the modern electric generators. In treatise on electricity and magnetism (1873), James Clerk Maxwell published the unified theory of electricity and magnetism through Maxwell's equations.

Thomas Alva Edison found in 1870 the electric lighting solution by using incandescent light bulb. In 1882 Edison opened the Electric Light Company, the first public electric power plant to supply 110 volts direct current (DC) for the lights. In Westinghouse the first hydroelectric power plant opened in 1882.

Nikola Tesla invented the Tesla coil in 1883. In order to transmit the electric power through this type of transformer the low voltage is changed to high voltage. An induction motor supplied from the alternating current was developed by Tesla in 1887.

George Westinghouse developed the first multiple-voltage alternative current (AC) power distribution system by using the transformers, in 1886. The electric energy was produced from the hydroelectric generator. Westinghouse imported the transformers and Siemens AC alternators (generators) from Europe and formed Westinghouse Electric & Manufacturing Company in 1886, a power distribution plant.

Galileo Ferraris was the "Father of three-phase current" (1885). In 1888, Galileo Ferraris published the work on the AC polyphase motor.

In 1889, Mikhail Dolivo-Dobrovolsky invented the cage version of the three-phase induction motor and in 1890 the wound rotor version of the actual three-phase induction motor.

Nowadays, the power transmission over long distance is reliable in AC power system. It requires high voltage obtained by using transformers conducting to low currents; therefore, low transmission losses occur. However, by introducing the static power converters, the DC transmission becomes a challenge.

The generation of the electricity mostly takes place into a power station by using the electromechanical generators. The primary sources of the generators are heat engines fueled by fossil sources or nuclear fission but also by renewable energy: wind, water motion energy, solar or geothermal power.

5.2 Static power converters

The development of power electronics starts with French scientist J. Jasmin. Jasmin discovered in 1882 that the mercury electric arc assures conduction in one way [25]. By using this property, the rectifier had been born transforming alternating current (AC) in direct current (DC). In 1892, L. Arons invented the vacuum valve with mercury arc. In 1906, J. A. Fleming invented the vacuum diode. The silicon valve was invented by G. W. Pickard in 1906. The vacuum triode was invented by L. de Forest in 1907. The first production of ignitrons was made by Westinghouse Company in 1933. Starting with the transistor invention in 1948, the next generation of power converters arises. The silicon controlled rectifier (SCR) or thyristor,

was invented in 1956 (John Moll). During 1956–1975, the power converters based on SCRs had been developed.

The new generation (1975–1990) of the power converters starts with new invented power switches: MOSFETs (metaloxide-semiconductor field-effect transistor, 1980), bipolar transistors and power bipolar junction transistors (BJT), the power gate turn-off (GTO) thyristors. The next generation of the power converters starts with the microprocessors, and application specified integral circuits (ASIC). The automatic control of power converters improves significantly the performances. The introduction of the intelligent power modules (IPM) boosts the performances of the power converters.

The main types of power converters are: rectifier, dc-dc chopper, inverters, direct (cycloconverters and matrix converters) and indirect (back-to-back) frequency converters. From commutation point of view, the power converters are natural commutated and force commutated. The phase-controlled rectifiers are natural commutated and used at high power. Due to the power quality problems, the performances are lower than of the force commutated power converters.

Besides of the development of the power devices and of the drivers, the modulation strategy is a key factor of efficiency improvements allowing the increased power capacity. The most common modulation strategy is pulse width modulation (PWM).

In order to obtain a variable speed, the alternating machines (synchronous and asynchronous) are combined with power converters. The most advanced control methods of the alternating machine are scalar control, vector control (field oriented), direct torque control, and sensorless control. The general exploration of the man-machine visual interactivity in the sense of the metaheuristic search algorithms can be a modern way for the energy domain exploitation. The modern algorithms based on artificial intelligence to find the optimal solution are also applied in this stringent energy area.

The features of the modern drives include remote control, networking, human-machine interface functions [26].

The new power converters should be protected against threats due to the digital communication and control. Therefore, the cybersecurity for the smart power converters should be taken into account [27]. Artificial intelligence and machine learning algorithms will be part of modern drive control systems.

5.3 Overview of the of the energy system

By knowing the input (energy production) and the output (energy consumption) of the the energy system the adequate mathematical model can be deduced. Taking into account the energy production (**Figure 3**—net electricity generation was 3.10 million GWh in 2016 [28]) from primary sources and the final energy consumption (**Figure 4**—EU 2016 energy consumption 2.78 million GWh) the main *energy conversion technologies* can be described briefly.

The hot water from the geothermal natural sources is used in steam power plant to obtain the electricity. The kinetic and potential energy from the rivers are transformed in electric energy through the hydro power station. The windmill captures the power of air flow to obtain the mechanical power. The mechanical power is converted into electricity by using the electric generators. The nuclear power plant used the nuclear energy to obtain the electricity. The photovoltaic cells are used to convert the solar energy into electricity. The most pollutant power conversion technologies are based on the fossil fuels. The transport sector is the most dominant consumption one where the fossil fuels are dominant, followed by the industry sector and households (**Figure 4**) [29]. Therefore, alternative energy solutions as

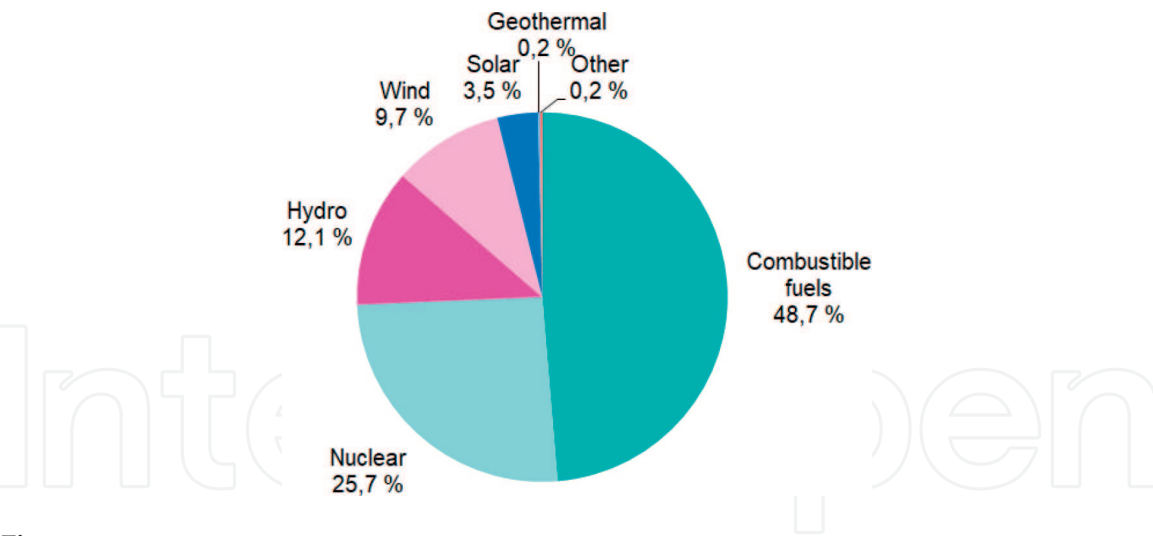


Figure 3.
Energy production [28] (% of total, based on GWh), EU-28, 2016.

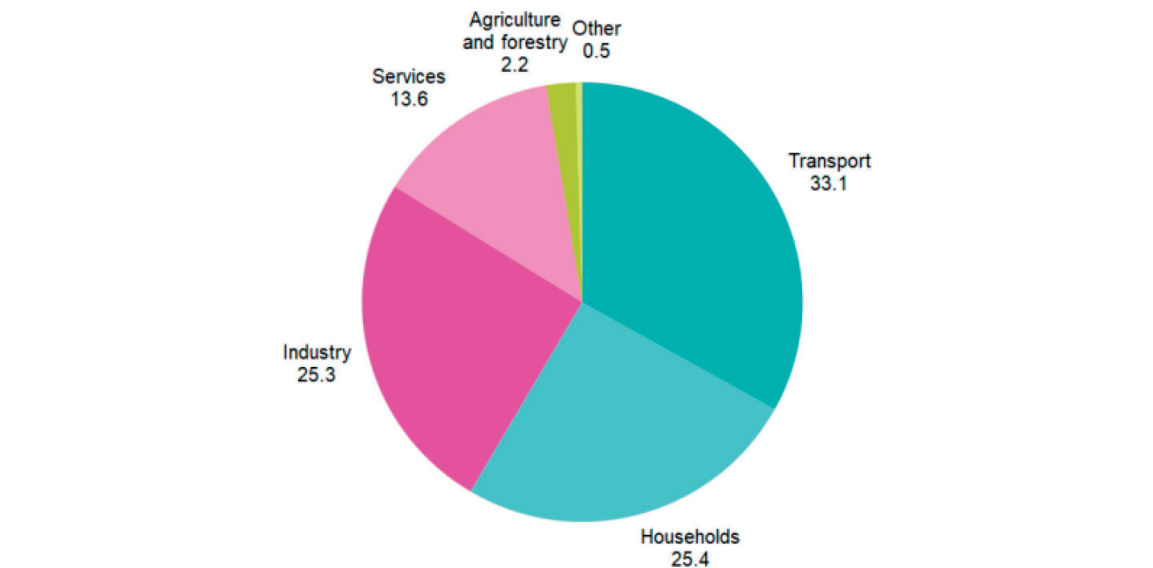


Figure 4.
Energy consumption [29] (% of total, based on GWh), EU-28, 2016.

environmentally friendly way should be taken into account. The prediction of the world energy consumption between 2010 and 2040 is an increase by 56% [30]. Currently, almost the entire world energy production is covered by hydropower plants, thermal power stations, and nuclear power plants. The environmentally friendly renewable energy will expand in the future.

The first optical amplification of the light based on stimulated emission of electromagnetic radiation, known as light amplification by stimulated emission of radiation (LASER) was invented in 1960 by Theodore H Maiman. The application of laser could be in energy transmission between the space stations and earth or could be used for the propulsion of the spatial vehicle [31].

Recently (2018), the Lawrence Livermore National Laboratory (LLNL) has obtained record of 2.15 megajoules (MJ) of energy with the National Ignition Facility (NIF) laser system [32]. The main purpose of NIF is to produce “green” electric power by fusion without producing radioactive waste.

Nobel prize in physics 2014 was awarded for the invention of the blue light-emitting diodes (LEDs), helped to create energy-efficient light sources in a completely new way. The impact of discovering white LED lamps will decrease significantly the world’s electricity used for lighting [33].

The extreme light infrastructure—nuclear physics (ELI-NP) pan European project has the main outcome the highest intensity laser system consisting of two 10 PW laser arms. The laser system will develop laser beam of 10^{23} W/cm² power intensity and up to 10^{15} V/m electrical fields [34]. The current record is HERCULES Petawatt laser at the University of Michigan, USA. The focused laser beam has the intensity of 2×10^{22} W/cm² [35, 36]. For a comparison, the strength intensity of the lightning electric field is 3×10^6 V/m (30 kV/cm) under dry air condition, at atmospheric pressure [37, 38]. The methods of measuring of these strength fields are described in [39]. The project ELI-NP was promoted by Professor Gérard Mourou in 2006 [40], one of the winners of the Nobel prize in physics 2018 [41]. By using laser technology, laser power transfer will be a solution to power the space vehicles or interplanetary communications.

6. Cyber physical systems

In order to increase the safety, security and reliability of the electricity the entire systems of energy domain should integrate the modern cyber-security features. Cyber physical systems (CPS) are based on the special architecture [42].

Two key enabled factors conduct to the design of modern energy plant infrastructures:

1. due to the limited flexibility and vulnerability of the ancient bulk centralized power systems;
2. protecting the bidirectional (receiving the adequate signals from the devices, transmitting the adequate control signals) communication data.

According to [43], there are two main causes that enable major changes to the electricity infrastructure:

- Environmental sustainability
- Effective management of pervasive data and extracted information

Two deterministic CPS models are described in [44], and used for practical realization of the distributed CSP through two projects: PRET (precision timed (PRET) computation in cyber-physical systems) [45], and Ptides (programming temporally-integrated distributed embedded systems) [46].

The pathways of the cyber physical systems developing should conduct to open CPS (cyber-physical systems) platforms [47]. The vision or short-term research strategy of any country should include the integration into Continental Cyber Physical Platforms (CCPP), respectively Intercontinental Cyber Physical Platforms (ICCPP). One development direction already started through the Open Source Cyber Platform [47]. At the same time, one of the European initiatives is made by the European Strategy Forum on Research Infrastructures [48].

Some of the main CPS design features could be mentioned as follows: to be modular, easily interconnecting with other CPS (plug and play), communication, self-healing, restoration, resiliency, autonomy, robustness, sensor-connectivity, and security assurance.

In order to ensure world protection against internal or external attacks, the synergies between the local CPS should be enabled, integrating in one intercontinental platform (ICCPP). One of the European projects has as main objective to disperse the CPSs to market through the seven platforms [49].

According to [50], the information about the current continental research platform in Europe is available. The European research infrastructures in Energy area could be finding on [51].

7. Conclusion

As the electric energy has the great importance for human development, in order to obtain it, any research strategy should include the electric power conversion development. Nowadays, the symbiosis between energy and information and communications technology is already taken into consideration. However, one key success of fast technology developing is the sharing of knowledge through open source. All the budget funded research projects should provide back the accumulated research results to the entire world. A win-to-win mechanism to access the high-tech laboratories by the worldwide researchers has been already created at least by the European Parliament and US officials. Another key-enabled of fast technology developing is the adequate training of the human resources through the advanced and innovative teaching, and researching methods. The curriculum development and adequate tools for education should be adapted very fast from the Digital Era [52] to the forthcoming Cyborg Era [53].

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