Chapter 14

Physical Principles of the Photovoltaic Energy Conversion: Temperature Dependences of PV Cell Parameters

Martin Libra
Czech University of Life Sciences, Czech Republic

Vladislav Poulek
Czech University of Life Sciences, Czech Republic

ABSTRACT

This chapter describes how the I-V characteristic of illuminated PV cells varies with temperature changes. The effect is explained according to the solid states theory. The higher temperature, the lower open-circuit voltage and the higher short-circuit current. This behavior is explained on the basis of band theory in solid-state physics. The increasing temperature causes a narrowing of the forbidden gap and a shift of the Fermi energy level toward the center of the forbidden gap. Both of these effects lead to a reduction of the potential barrier in the band diagram of the illuminated PN junction, thus to decrease of the photovoltaic voltage. In addition, the narrowing of the forbidden gap causes higher generation of electron-hole pairs in the illuminated PN junction and short-circuit current increases. The efficiency of the PV energy conversion decreases with the increasing temperature.

PHYSICAL CHARACTERISTICS OF LIGHT

Light is taken as something absolutely commonplace and we usually do not dwell on its physical nature. Yet this issue is both interesting and complex. In antiquity, scientists started dealing with the problems of optical projection already. More fundamental study of the essence of light started only in 17th century. In 1678 Christian Huygens (1629-1695) presented a paper characterising light as longitudinal wave motion at the Paris Academy. However, Sir Isaac Newton (1643-1727) described light as flow of particles; his pre-eminence resulted in the corpuscular theory of light dominating until the end of 18th century. The

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19th century saw rapid development of the wave theory, supported by the experiments with interference and diffraction and by new scientific discoveries in the field of electricity and magnetism.

We know today that light is formed by transverse electromagnetic waves in a fairly narrow wavelength range, and at the same time it appears as a flow of photons. Thus, both theories are applicable. This level of understanding is the result of lengthy development of knowledge. Systematic research in the field of electric power could start only after the 1799 invention of a galvanic cell by Alessandro Volta (1745-1827). Hans Christian Oersted (1777-1851) discovered in 1820 that electric current creates a magnetic field around it and that electricity and magnetism are somehow connected. Later on, André-Marie Ampère (1775-1836), predicted and proved the mutual force interaction of electric currents and formulated the Ampère Law. Michael Faraday (1791-1867) discovered electromagnetic induction and formulated the Faraday Law.

This prepared the ground for James Clerk Maxwell (1831-1879), who was able to summarise in his four equations all that had been discovered in the field of electricity and magnetism, and to formulate thus the unified theory of electromagnetism (Halliday et al. 2001). His equations show that change of electric field in time induces a magnetic field and vice versa, the change of magnetic field in time induces an electric field. Both fields propagate in the form of waves travelling at the finite speed of light \(c\). The product of the permittivity and permeability of the environment is equal to the value of the inverse square of the speed of light. Electromagnetic waves were predicted much earlier than they could be proven experimentally. The correspondence between the speed of spreading of these waves and the measured speed of light was so astounding, that it led Maxwell to the conclusion that these waves represent the nature of light. He was able to infer the basic laws of physical optics from his equations and thus unify the theory of optics with electromagnetic field theory.

Maxwell’s theory met with great scepticism for a considerable time. Electromagnetic waves were not proved experimentally and their existence seemed highly improbable to physicists. Maxwell himself did not live long enough to see the triumph of his theory. Nine years after his death, Heinrich Rudolf Hertz (1857-1894) was able to prove the existence of electromagnetic waves in an experiment involving electrical discharge between two cusped electrodes – he was able to detect a response in an antenna. He proved the existence of electromagnetic waves with wavelengths shorter than one metre, but did not see any practical application for his discovery. Of course, a key application was discovered by Marconi, Tesla and Popov with their invention of wireless telegraphy. Today we can see countless other applications.

Electromagnetic waves ceased to be a mere hypothesis and became a part of the integrated electromagnetic field theory. The form of such a wave can be seen in Fig. 1. As described above, a change in an electric field in time induces a magnetic field and vice versa. For the linearly polarized light the vectors of intensity of the electric field and the induced magnetic field are oscillating in mutually perpendicular directions and each induces the other. Longitudinal wave motion is spreading perpendicularly to both these vectors.

Common light is non-polarized, i.e., the vectors \(\vec{E}\) and \(\vec{B}\) of individual waves change their orientation chaotically (randomly). If the projection of vector \(\vec{E}\) into the polarization plane (a plane perpendicular to the direction of propagation) is an abscissa (straight line), we speak about a linearly polarized light. In the case when the terminal point of the vector circumscribes a circle or an ellipse in this plane, the light is circularly or elliptically polarized.

Electromagnetic waves (or electromagnetic radiation) can have wavelengths in a very broad range from \(10^{-13}\) m or shorter to hundreds or thousands of metres or even longer. Visible radiation (or light)
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