Assessing Electrical Systems via Exergy: A Dualist View Incorporating Technical and Environmental Dimensions

MARC A. ROSEN [1] CORNELIA AIDA BULUCEA [2]

[1] Faculty of Engineering and Applied Science
University of Ontario Institute of Technology
2000 Simcoe Street North, Oshawa, Ontario, L1H 7K4
CANADA

[2] Faculty of Electromechanical and Environmental Engineering
University of Craiova
ROMANIA

marc.rosen@uoit.ca, abulucea@gmail.com

Abstract: Traditionally, the basic concepts of energy, exergy and embodied energy are founded in the field of physics. But since these concepts have environmental, technical and economical significance as well, it may be advantageous to explain, interpret and apply them in a more universal manner in line with their multidisciplinary traits. Some argue that science not clarified and unified technical and ecological viewpoints. To address meaningfully many of the problems facing humanity today, a set of conditions for the performance of sustainable technical systems must be formulated. Here, the benefits are demonstrated of using exergy concepts to understand the efficiencies of electrical technologies and systems and to guide improvement efforts. Although exergy applications in electrical engineering are uncommon, exergy clearly identifies efficiency improvements and reductions in thermodynamic losses for electrical technologies and systems. Hence, the research reported here aims to demonstrate, in terms of sustainability, the usefulness of the embodied energy and exergy concepts for analyzing electric devices which convert energy, particularly the electromagnet. To accomplish this objective, a dualist view is adopted, incorporating technical and environmental dimensions. The information provided by energy assessments is shown to be less useful than that provided by exergy and prone to be misleading. It is concluded that exergy has a significant role to play in evaluating and increasing the efficiencies of electrical technologies and systems, and should prove useful to engineers as well as decision and policy makers.

Key-Words: Electrical engineering, electromagnet, embodied energy, energy conversion, exergy, magnetic field, magnetic forces, mechanical work.

1 Introduction

Within a framework of sustainable development, the exergy concept, which is a measure of energy quality, can be used to enhances understanding and help improve the efficiencies of technical systems which convert energy and matter [1-6]. According to the laws of thermodynamics, energy is never destroyed during a process, although it can change from one form to another, but exergy can be destroyed. While energy is a measure of quantity only, exergy is a measure of quantity and quality or usefulness. Exergy is a measure of the potential of a system to do work. Exergy analysis overcomes many of the deficiencies of energy analysis, identifying properly the causes, locations and magnitudes of inefficiencies. Thus, exergy has an important role to play in increasing efficiencies of energy systems and technologies, within energy optimization and engineering modeling studies. Exergy can also identify better than energy the environmental and economic benefits of energy technologies [4].

Many feel that exergy is applicable only to systems or studies involving thermodynamics, in areas like mechanical and chemical engineering [7-10]. Consequently, the full value of exergy is not achieved because it is neglected or underutilized in other fields. One such area is electrical engineering, where exergy applications are uncommon.

Sustainability concepts can be applied in a simple way within the framework of "industrial ecology." Such an approach provides an alternative view of systems and equipment which convert energy and materials [11-16]. Industrial ecology seeks analogies between anthropogenic technical systems and natural ecosystems and, on a more holistic level, considers industrial systems and ecological systems as parts of the same overall system, the industrial ecosystem. An important implication of this approach is that the behaviour and laws of natural systems should be used in assessing the viability of human technical systems, according to the model of an ecosystem.

This paper goes on to describe exergy and exergy methods as well as their applicability to electrical devices. Examples are used to illustrate the use of exergy as a tool to understand and improve efficiency. The objective is to understand better how efficiencies, energy flows and exergy losses for electrical systems, thereby assisting efforts to improve them.

2 Dualist View of Electromagnets

Many examples can be used to demonstrate how exergy methods improve understanding of efficiencies and help increase them. This paper presents an overview of the operation of electromagnets, which are not only an element of many control and protection electrical devices (e.g., constituting the motor element in electromagnetic contactors, relays, circuit-breakers and switchers), but also a small-scale system. In the dualist view taken here, the electromagnet system is taken to be surrounded by two environments: a technical one and an ecological one. Within the technical surroundings, the electromagnet system is closed, whereas within the ecological environment the electromagnet is seen as an open system. The gradient relative to the electromagnet surrounding reference frame is observed as different from the structure of the device and its reference environment. This consideration implies that the "energy losses" is only a correct notion only taking into account the technical reference frame. For the ecological reference frame, more appropriate terms are "energy flows" and "exergy losses".

In line with these concepts, it would be useful to determine the analogies between the ecosystems and electrical systems regarding the key features of structure and function. One significant feature is that the changes in ecosystems are not continuous. A second feature emphasizes that the changes, seen as ecological loops, have temporal scales varying from slow accumulation to abrupt release of that capital. The latter can occur at specific times or at locations of increased vulnerability. In this paper, starting from these assumptions, we approach with a dualist view two essential aspects in the electromagnet theory: (1) assessing the energy embodied in the field of a electromagnet without elements in motion (i.e., an electromagnet with an immobile armature) and evaluating, on this basis, the static and dynamic inductances of the circuit; and (2) exergy analysis on the basis of the useful mechanical work developed by the magnetic field forces when the electromagnet armature is in motion.

2.1 Energy and Exergy Balances

An industrial ecosystem does not have a single equilibrium point. Rather, the system moves among multiple stable states. The transient regime of an electromagnet supplied by a constant voltage source represents a system movement between two points of equilibrium. We consider an electromagnet with a ferromagnetic core and an immobile armature [17-19]. The excitation coil (made from copper Cu) with w turns has an electric resistance r [in Ω]. At the instant (at time t = 0) the excitation winding is connected to a constant voltage source $U = ct.$, a current i appears, which increases from a value of 0 (the first stable state of this industrial ecosystem) to the steady-state regime value $I_s = U/r$ (the second stable state), following the curve shown in Fig. 1.

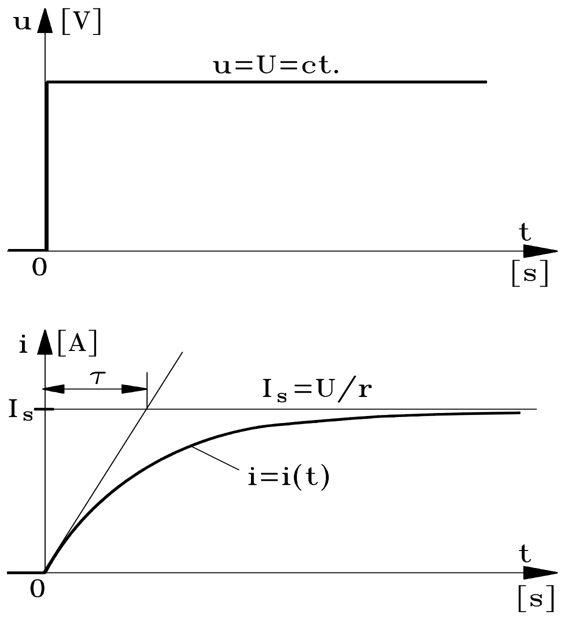

Fig. 1. Evolution in transient regime of the electromagnet winding current when the ferromagnetic core is fixed.

In the current diagram $i = i(t)$ in Fig. 1, the quantity $\tau = L/r$ represents the delay time electric constant of the circuit. Normally, the current i

reaches the steady-state regime value I_s after 4τ to 5τ.

From the physical-technical viewpoint, during the transient regime, all electromagnetic processes of the circuit are governed by the Electromagnetic Induction Law. Consequently, the following equations are obtained:

$$-U + r \cdot i = e$$
$$e = -\frac{d\psi}{dt} \quad (1)$$
$$\psi = w \cdot \phi$$

Consequently, we can write $U = ri + d\Psi/dt$, which indicates that the applied voltage to the electromagnet winding terminals is balanced in the transient regime by the drop voltage ri on the coil resistance and by the electromotive back force $-e = d\Psi/dt$ induced in the coil. The latter is caused by the total flux variation $\Psi = w\Phi$, where Φ denotes the fascicular flux.

With these expressions, the energy balance of the electromagnet can be obtained during the transient regime within the technical reference frame:

$$\int_0^t U \cdot i \cdot dt = \int_0^t r \cdot i^2 \cdot dt + \int_0^\psi i \cdot d\psi \quad (2)$$

or

$$W = W_J + W_m \quad (3)$$

where $W = \int_0^t U \cdot i \cdot dt$ represents the electric energy provided by the supply source, $W_J = \int_0^t r \cdot i^2 \cdot dt$ represents energy losses by the Joule effect, and $W_m = \int_0^\psi i \cdot d\psi$ is the energy embedded in the magnetic field.

We establish subsequently the exergy balance for the same transient regime, noting that exergy is a measure of the potential of a system or flow to cause change, as a consequence of not being completely in stable equilibrium relative to a reference environment. Unlike energy, exergy is not subject to a conservation law (except for ideal, or reversible, processes). Rather exergy is consumed or destroyed, due to irreversibilities in any real process. Within the ecological reference frame it is instructive to not refer to energy losses, but rather to express energy flows and exergy losses. The exergy balance within the ecological reference frame can be written on the basis of the input-output method as

$$X = X_J + \Delta X_m \quad (4)$$

where X represents the input exergy, X_J the destroyed exergy (by the Joule effect) and ΔX_m the embedded exergy (or embodied or stored energy) in the magnetic field of the electromagnet.

Consequently, the magnetic field exergy can be obtained from the input exergy after the exergy losses (in the coil) are determined.

After the transient regime, the winding current reaches the steady-state value $I_s = U/r$ and the magnetic flux also attains a constant value corresponding to the stable regime $\Psi = ct$. This regime begins at the moment when $d\Psi = 0$ and the electromagnet system reaches a new equilibrium point. In this stable state the energy embedded in the magnetic field remains constant and all the energy from the source W offsets coil conductor exergy losses X_J.

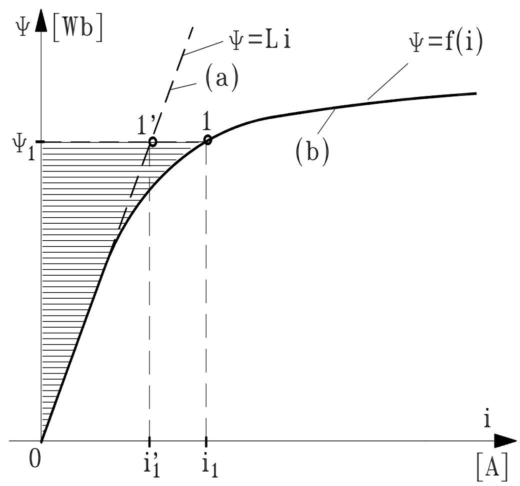

Fig. 2. Electromagnet characteristic $\psi = f(i)$: (a) coil in the air; (b) coil on the ferromagnetic core.

The destruction of exergy during the transient process between the two equilibrium points is not caused only by the electromagnetic coil. Since the total magnetic flux (of the winding with w turns) $\Psi = w\Phi$ depends on the fascicular magnetic flux Φ = BS and because the induction curve B = f(H), corresponding to the iron core magnetizing characteristic, which is non-linear, the resulting total flux Ψ depends on the current, i.e., $\Psi = f(i)$. The corresponding a curve is represented in Fig. 2. The linear dependence indicated at position (a), corresponding to the straight line $\Psi = Li$ with $L = ct$, corresponds to the excitation coil without a ferromagnetic core (coil on the air).

Also, the non-linear curve $\Psi = f(i)$ shown at position (b) corresponds to the winding on a ferromagnetic core. The shape of curve (b) reflects the non-linearity of the iron core magnetizing characteristic and depends both on the dimensions and type of the core material, and on the total magnitude of the electromagnet air gap.

Corresponding to the non-linear curve $\Psi = f(i)$ at position (b), the magnetic field embodied energy ΔX_m (in the case of a constant air gap) corresponds to the hatched surface in Fig. 2. That is,

$$\Delta X_{m1} = \int_0^{X_1} i \cdot d\psi = surface\,(01\psi_1) \qquad (5)$$

For any point on the characteristic Ψ = f(i), the ratio between the total magnetic flux Ψ and the current i, which is positive, represents the static inductance L_s (see Fig. 3):

$$L_s = \frac{\psi(i)}{i} > 0$$
$$L_s = L_s(i) = tg\alpha \qquad (6)$$

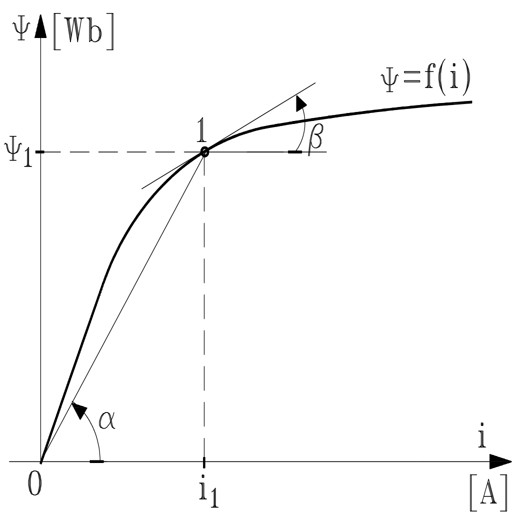

Fig. 3. Defining static inductance L_s and dynamic inductance L_d using the variation of total magnetic flux with current.

The static inductance L_s is variable and depends on the current i, as shown in Fig. 4.

In the case of windings on a ferromagnetic core, we define the dynamic inductance L_d (see Fig. 3) by the relations:

$$L_d = \frac{d\psi}{di}\Big|_{i=i_1};\ L_d = L_d(i) = tg\beta \qquad (7)$$

For instance, if dL/dt = 0 (i.e., when L it is independent of time), the inductance necessary according to the Electromagnetic Induction Law is the dynamic inductance L_d:

$$e = -L\frac{di}{dt}$$
$$L = \frac{-e}{\frac{di}{dt}} = \frac{-(-\frac{d\psi}{dt})}{\frac{di}{dt}} = \frac{d\psi}{di} = L_d \qquad (8)$$

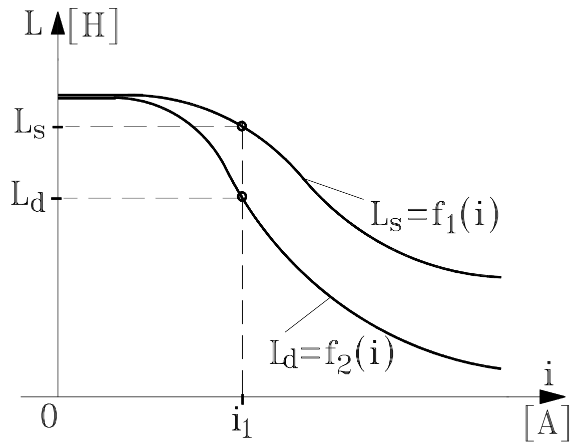

Fig. 4. Curves of static $L_s = f_1(i)$ and dynamic $L_d = f_2(i)$ inductances as a function of current.

The dynamic inductance L_d is variable and depends on the current i (see Fig. 4). During the transient process of the industrial ecosystem movement among multiple stable states, therefore, we must work with the dynamic inductance rather than static inductance (Fig. 4), taking into account all further technical consequences.

2.2 Useful Mechanical Work of Armature in Movement

For any electromagnet with embedded energy in the ferromagnetic core, the electromagnetic forces draw the armature to the core and reduce the air gap as a result.

In the evaluation of the mechanical work W_{12} caused by the magnetic field forces (when the armature is in movement), we consider an electromagnet characterized at the initial equilibrium point by the air gap magnitude δ_1 and the flux curve $\Psi = f_1(I)$ on which, in the first stable regime, the operation has been stabilized at point 1, with the coordinates I_1 and Ψ_1 (see Fig. 5a).

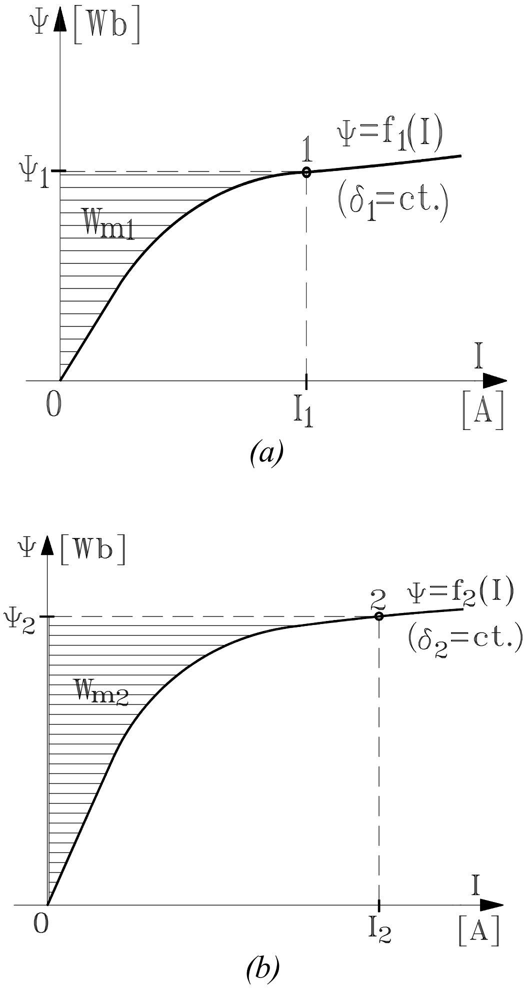

Fig. 5. Characterization of initial (a) and final (b) stable states of the electromagnet with the armature in motion.

After the armature attraction, the final stable state is described by the air gap δ_2 (with $\delta_2 < \delta_1$) and by the flux characteristic $\Psi = f_2(I)$, on which is found the second equilibrium point (point 2), with coordinates I_2 and Ψ_2 (Fig. 5b).

With Equation (4), the energy embedded in the magnetic field in the initial state W_{m1} and the final state W_{m2} is proportional to the hatched surfaces in Fig. 5. That is,

$$W_{m1} = \int_0^{\psi_1} i \cdot d\psi = surface\,(01\psi_1) \qquad (9a)$$

$$W_{m2} = \int_0^{\psi_2} i \cdot d\psi = surface\,(02\psi_2) \qquad (9b)$$

Moreover, it is assumed that the evolution from initial state 1 to final state 2 occurs slowly, according to the ecosystem exergy accumulation in the loop, so that all intermediary states are stationary.

Therefore, in the frame (I, Ψ), all intermediary balance points are on the curve between points 1 and 2, $\Psi = \Psi(I)$, as illustrated in Fig. 6.

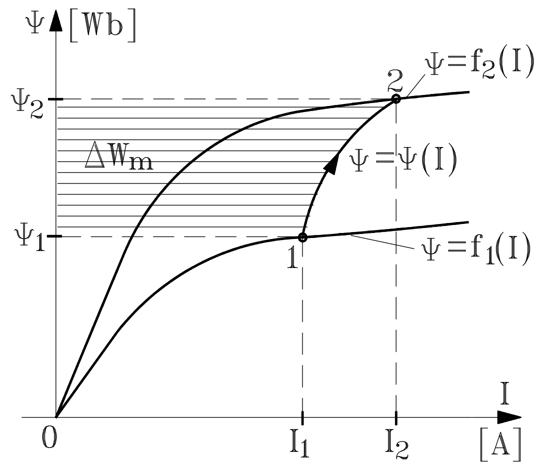

Fig. 6. Evolution curve $\psi = \psi(I)$ and the change in magnetic energy ΔW_m when the armature moves.

In these conditions, during the armature movement (from δ_1 to δ_2), a dual energy change occurs between the source and the magnetic field. First, the source provides to the electromagnet the change in energy ΔW_m, proportional to the hatched surface corresponding to the flux variation from Ψ_1 to Ψ_2 on the evolution curve $\Psi(I)$ in Fig. 6:

$$\Delta W_m = \int_{\psi_1}^{\psi_2} i \cdot d\psi = surface\,(\psi_1 12 \psi_2) \qquad (10)$$

Second, the magnetic field forces perform mechanical work W_{12}, corresponding to the displacement $\Delta\delta$ of the electromagnet armature.

Consequently, in the absence of the dissipative magnetic forces, the energy balance of the electromagnet in the technical reference frame, under the varying conditions of the state-quantities due to the armature movement, is described by the following equation:

$$W_{m1} + \Delta W_m = W_{m2} + W_{12} \qquad (11)$$

Within the reference frame of industrial ecology, it is helpful to write the exergy balance for the previous situation on basis of input-output analysis:

$$X_{in} + \Delta X_{sys} - X_{out} - X_{des} = 0 \qquad (12)$$

where X_{in} is the input exergy, corresponding to the magnetic field embodied energy in the initial stable state; ΔX_{sys} is the change in exergy of the system during the transient process; X_{out} represents the output exergy (including both the magnetic field embodied energy in the final stable state and the net transfer exergy by useful mechanical work); and X_{des} is the exergy destruction by the dissipative magnetic forces of the system.

Neglecting the exergy destroyed by dissipative forces, the meanings of equations (11) and (12) are similar, but they are expressed in physical-technical and ecological terms, respectively. The use of exergy, as noted earlier, provides insights into environmental and ecological impact.

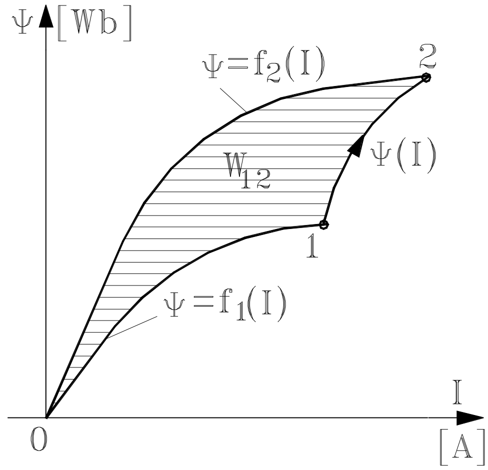

Fig. 7. Mechanical work W_{12} at armature movement.

The mechanical work performed, which can be expressed as $W_{12} = W_{m1} + \Delta W_m - W_{m2}$, can be illustrated graphically with equations (9) and (10):

$$W_{12} = surface\,(01\psi_1) + surface\,(\psi_1 12 \psi_2) - \\ - surface\,(02\psi_2) = surface\,(012) \quad (13)$$

The mechanical work W_{12} performed by the magnetic field forces when the electromagnet armature is in motion is equal to the surface (012) in Fig. 7, bounded by the curves $\Psi = f_1(I)$, $\Psi = f_2(I)$ and by the evolution curve $\Psi = \Psi(I)$. The area (012) is represented by the hatched surface in Fig. 7.

In the coordinates frame ($IO\Psi$), the most simple evolution curves $\Psi(I)$ from stable state 1 to stable state 2 are parallel straight lines with the axes (see Fig. 8):

- at a constant current $I = I_1$ = const., when the evolution is described by the straight line $\overline{12'}$ or
- at a constant flux $\Psi = \Psi_1$ = const., when the evolution follows the straight line $\overline{12''}$.

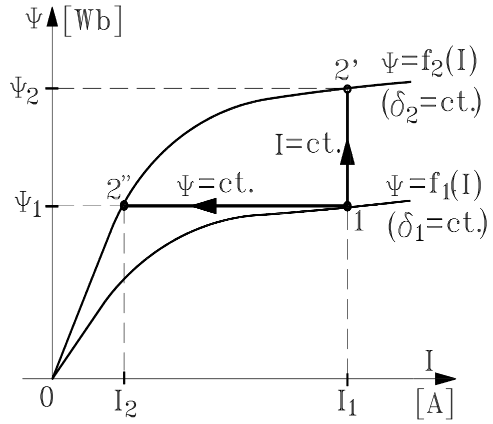

Fig. 8. Two particular evolutions $\psi = \psi(I)$: 1-2'(at I = const.) and 1-2" (at ψ = const.).

In such cases, the mechanical work W_{12}, on the basis of the graphical interpretation described earlier, can be approximated with the following relations:

a) $W_{12} = W_{12'}$ at I = const. (when the evolution is along the straight line $\overline{12'}$), where

$$W_{12'} = surface(012') \approx \\ \approx \frac{1}{2}(\psi_2 - \psi_1) I_1 = \frac{1}{2}\Delta\psi_{12} I_1 \quad (14)$$

b) $W_{12} = W_{12''}$ at Ψ = const. (when the evolution is along the straight line $\overline{12''}$), where

$$W_{12''} = surface(012'') \approx \frac{1}{2}\psi_1 (I_1 - I_2) = \\ = -\frac{1}{2}\psi_1 (I_2 - I_1) = -\frac{1}{2}\psi_1 \Delta I_{12} \quad (15)$$

Once again, an analogy exists between technical systems and ecosystems. People have discovered the laws of nature and used them in engineering applications. The concepts we are use describe the characteristics of nature (e.g., features, quantities and parameters). We consider, for instance, that parameters in the field of electromagnetism also have significance as environmental parameters. So, taking into account an ecosystem model, the electromagnet can be thought of as in an industrial ecosystem, where it can perform mechanical work with a magnitude depending on environmental parameters, e.g., electric current intensity and magnetic flux density.

3 Discussion

Several points are highlighted in this analysis:

1. Due to the existence of two inductances (static L_s and dynamic L_d), the "risk" of the double

ISSN: 1790-2769

ISBN: 978-960-474-100-7

interpretation appears often. Only if the coils do not have a ferromagnetic core (when $\Psi = f(i)$ is a straight line) are the two inductances (static and dynamic) the same, i.e., $L_s = L_d = L$ and $\Psi = Li$. This result implies that, during the transient process of the industrial ecosystem moving among multiple stable states, it is advantageous to work with the dynamic inductance instead of static inductance.

2. Graphical interpretations have been obtained theoretically of the classical formulas for the calculation of mechanical work, both at constant current (I = const.) and at constant flux (Ψ = const).

Once again an analogy is observed between the technical system and an ecosystem. People have used laws of nature in engineering applications, and concepts, characteristics and features associated with natural phenomena are utilized in engineering applications in what we refer to here as technical regimes. In addition, we need to consider that many quantities and parameters in the field of electromagnetism also have significance relative to the ecological surroundings. So, taking into account the ecosystem model, the electromagnet device as an industrial ecosystem can perform mechanical work with a magnitude that depends on electric current and magnetic flux. These last two quantities are examined further in relation to the environmental perspective of this paper.

Although electric current and magnetic flux are technical quantities defined within electromagnetism theory, they have environmental relations and as such arguably may be viewed as environmental parameters. Usually, we characterize the environment through such classical parameters as its temperature, pressure, volume, humidity, etc. In recent decades, numerous studies have been reported that suggest we also need to consider electromagnetic waves as environment quantities. For instance, a study [20] performed in 2002 by Spectrum Management assessed the electromagnetic field intensity in the city of Toronto, Canada. In the investigation, electromagnetic field intensity levels were measured within the frequency range 150 kHz to 3 GHz at selected locations. The results emphasized that human activities, such as maritime and aeronautical services, television broadcast, wireless cable TV or cellular and paging, are increasing the environmental impacts caused by electromagnetic field intensity levels. Also, we know that radioactive materials, both natural and anthropogenic (e.g., materials artificially created by people during nuclear activities) can emit gamma rays. Electromagnetic waves exist not only because of human activities, but also due to natural sources in the Universe. For example, the Sun is a source of ultraviolet (UV) radiation, and the full Moon and stars, and other “hot” objects in space emit UV electromagnetic waves. Radio waves, UV waves, gamma rays and all the other parts of the electromagnetic spectrum are fundamentally part of the Electromagnetic Field. The electromagnetic spectrum is usually expressed in terms of energy, wavelength or frequency, but we need to understand more about the environmental features of electromagnetic field quantities. This enhanced understanding may be achievable within the framework of Industrial Ecology, which permits an alternate viewpoint of human applications, related both to the technical and environmental reference systems. In line with this idea, a first step might be to view the magnetic induction (magnetic flux density) B and the electric current intensity I as environmental parameters.

3. With the general expression $W_m = \frac{1}{2} \cdot I \cdot \psi$ for the embedded magnetic energy, the mechanical work expressions $W_{12'}$ from equation (14) and $W_{12''}$ from equation (15) (performed by the armature in motion) can be written in a unitary mode with the following expressions:

$$W_{12'} = \Delta W_{m12}\big|_{I=ct.} \quad \text{and} \quad W_{12''} = -\,\Delta W_{m12}\big|_{\psi=ct.}$$

4 Conclusions

The benefits of using sustainability concepts to understand the efficiencies of systems and devices which use and convert electric energy and to guide improvement efforts have been demonstrated. The laws of nature should be used in assessing technical applications by applying the model of an ecosystem. It is concluded that the concepts encompassing exergy and embodied energy have a significant role to play in evaluating and increasing the efficiencies of such devices. Exergy should prove useful in such activities to engineers and scientists, as well as decision and policy makers.

The results suggest that exergy analysis and its application to many other devices that convert and use electrical energy or are driven by electricity merit further investigation, within the framework of industrial ecology, and such research is the subject of further investigations by the authors. As energy policies increasingly play an important role in addressing development and sustainability issues, decision and policy makers would also benefit from an appreciation the exergy concept and its applications.

Acknowledgments

Financial support for this research was provided by the Natural Sciences and Engineering Research Council of Canada.

References

[1] Moran M.J., *Availability Analysis: A Guide to Efficient Energy Use*, revised ed. New York: American Society of Mechanical Engineers, 1989.

[2] Szargut J., "International progress in second law analysis," *Energy*, vol. 5, pp. 709-718, 1980.

[3] Edgerton R.H., *Available Energy and Environmental Economics*. Toronto: D.C. Heath, 1982.

[4] Dincer I. and Rosen M.A., *Exergy: Energy, Environment and Sustainable Development*. Oxford, UK: Elsevier, 2007.

[5] Brodyanski V.M., Sorin M.V., and Le Goff P., *The Efficiency of Industrial Processes: Exergy Analysis and Optimization*. London: Elsevier, 1994.

[6] Yantovskii E.I., *Energy and Exergy Currents: An Introduction to Exergonomics*. New York: Nova Science Publishers, 1994.

[7] Rosen M.A. and Dincer I., "Thermoeconomic analysis of power plants: an application to a coal-fired electrical generating station," *Energy Conversion and Management*, vol. 44, pp. 2743-2761, 2003.

[8] Rosen M.A. and Dincer I., "Exergy analysis of waste emissions," *Int. J Energy Research*, vol. 23, pp. 1153-1163, 1999.

[9] Rosen M.A., "Energy- and exergy-based comparison of coal-fired and nuclear steam power plants," *Exergy, An International Journal*, vol. 1, pp. 180-192, 2001.

[10] Rosen M.A., Le M.N. and I. Dincer I, "Efficiency analysis of a cogeneration and district energy system," *Applied Thermal Engineering*, vol. 25, no. 1, pp. 147-159, 2005.

[11] Connelly L. and Koshland C.P., "Two aspects of consumption: using an exergy-based measure of degradation to advance the theory and implementation of industrial ecology," *Resources, Conservation and Recycling*, vol. 19, pp. 199-217, 1997.

[12] Szargut J., *Exergy Method: Technical and Ecological Applications*. Southampton, UK: WIT Press, 2005.

[13] Allenby B.R., *Industrial Ecology: Policy Framework and Implementation*. Prentice-Hall, New Jersey, 1999.

[14] Ayres R.U., Industrial Metabolism. In Ausubel, J.H. and Sladovich H.E. (eds): *Technology and Environment*, pp. 23-49, National Academy Press, Washington, 1989.

[15] Graedel T.E. and Allenby B.R., *Industrial Ecology*. Prentice Hall, New Jersey, 1995.

[16] Holling C.S., Schindler D.W., Walker B.W. and Roughgarden J., Biodiversity in the Functioning of Ecosystems. In Perrings, C., Maler K.-G., Folke C., Holling C. S. and Jansson B.-O. (eds), *Biodiversity Loss*, pp. 44-83, Cambridge University Press, 1995.

[17] Coulon I. and Jufer M., *Introduction à l'électrotechnique (Introduction to Electrotechnics)*, 5th edition, Piesses Politechniques Romandes, Laussane, 1989.

[18] Bulucea C.A. and Nicola D.A., *Introducere în electrotehnica si echipamente electrice (Introduction to Electrotechnics and Electrical Equipment),* SITECH Publishing House, Craiova, Romania, 2004.

[19] Nicola D.A. and Bulucea C.A., *Electrotehnica, masini si echipamente electrice (Electrotechnics, Electrical Machines and Equipment),* SITECH Publishing House, Craiova, Romania, 2005.

[20] Nguyen B., Mohabeer S., Lai V. and Lander E., Evaluation of Electromagnetic Field Intensity in the City of Toronto, Report for Industry Canada, Spectrum Management, Ontario Regional Engineering, Canada, June 2002.