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From Electrica to Invariant Automatica (Or how to use the concept Electrical Energy for enter into Theory of Invariant Automatic Control)

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I. PART ONE. SYSTEM AND INVARIANT ELECTRIC MODEL

A. Energy and System

The concept electrical energy has today so wide and vital use, that without him is impossible to speak for a normal everyday life in conditions of civilization. The mass user of electrical energy has not any interest how it is obtained. It is importantly for him the energy to be available always and everywhere when it is necessary.

Not so stands the question ahead of the producer of electrical energy. He knows that it is obtained by transforming of other aspects of energy (mechanical, thermal, hydraulic, thermonuclear, etc.). And the transforming itself must be controlled by human hand and that imposes on the producer to have a common view and measure for every aspect of energy that must be transformed in electricity. And to be the view of the narrow specialist electrical engineer sufficiently wide for the knowledge about the concept energy, let us to take a look at the energy from a dialectical viewpoint by

Axiom A1.1. Energy is a common measure for movement of the matter in dialectic sens of this concept.
Axiom A1.2. Matter exists only in state of movement.
From the axioms A1.1 and A1.2 follows the trivial proved
Theorem T1.1. Energy is a common measure for existence of the matter
Like a consequence from theorem T1.1 cannot renounce that the state of energetic of every human community (state, union, empire etc.) defines qualitatively and quantitatively the existence of its civilization. And in view of the fact that the characterization of every community requires a systematic method of approach, it is necessary to define the concept **system.**
Definition D1.1. System is every pair from the description of figure 1.1, when with **ES** is marked **energetic source** and with **EC** – energetic consumer.
System can be:

- natural fact: solar system (the Sun generating gravitational energy exchanged with planets around him), cardiovascular system (the heart supplying with blood every living organism for necessary living energy), nervous system (the brain sending commands by nerves to the organs of the living organism), atom system (the nucleus exchanging energy with the electrons around him) etc.;
- creation of the human community (energetic system, transport system, economic system, state system etc.).
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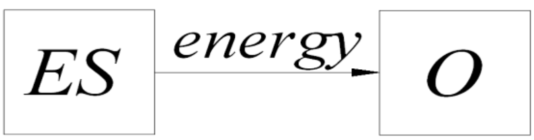

Figure 1.1

Axiom A1.3. A system (see fig. 1.1) can be controlled then and then only when are known the technical properties of the consumer and the energetic source and it is possible to change the energetic flow to the consumer according a human desire. With other words: **to control must now and can**.
Definition D1.2. An object O included in system (see figure 1.2) is controlled when it is an engine changing its outlet qualitative or quantitative property x of the material substance containing or passing trough him in the property x^0 by a change of the energetic flow E according the function $E = E(x^0)$. The property x^0 is choosed or programmed in the time t by human desire.

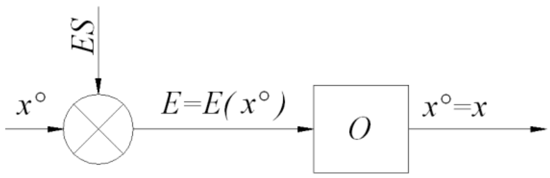

Figure 1.2

Definition D1.3. If the outlet property x of the system is a mathematic function of the real numbers the system is named **analog**, if it is a function of the integer numbers the system is named **discreet** (**numeric or digital**).
Definition D1.4. A system that is composed by:
- object with constant trough all working period parameters;
- energetic source with unlimited for all working period energetic reserves;
- energetic source with interminable in relation to consumed by the object power;
- constant quality of the energetic flow toward the object,

is named **invariable** and its parameters – its **invariants.**

B. **System *RLC* like a model of invariant system.**
1. Balanced (stable, permanent, continued) energetic process in a *RLC* system.

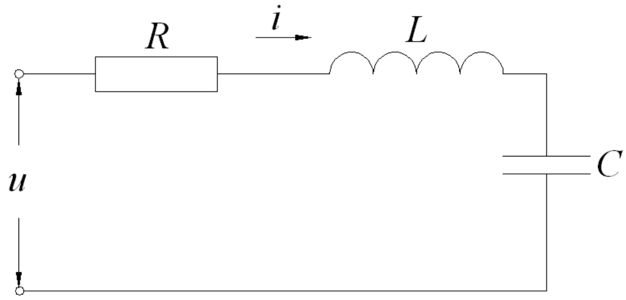

Figure 1.3. System *RLC* in stable mode

Definition D1.5. An invariant system is in state of balanced (stable) working mode when its action (in this case the current) is constant.
The generalized law of Ohm for the electric circuit on figure 1.3 defines the balanced state between the supplying voltage *u* of the source and the voltage falls in the same circuit about the equation:

(1.1) $$u = u_R + u_L + u_C = iR + L\frac{di}{dt} + \frac{1}{C}\int_0^t idt ,$$

where u_R, u_L and u_C are respectively resistive, inductive and capacitive voltage falls.
The supplying voltage can be a function in the time *t* periodic, periodic sinusoidal or continued.
When the supplying voltage u is periodic the *RLC* system consumes the full energy:

(1.1.1) $E_S = \sqrt{E_P^2 + E_Q^2 + E_D^2}$, when

E_P is active, E_Q – reactive and E_D – deforming component of energy. The three components constitute a tridimensional Euclidean space. Let name this space $\varepsilon(3)$
When the supplying voltage u is periodic sinusoidal the *RLC* system consumes the full energy:

(1.1.2) $E_S = \sqrt{E_P^2 + E_Q^2}$.

Here the deforming component $E_D = 0$ because there is not any deformation of the sinusoidal function $u(t)$ of the supplying voltage u . The two components constitute a two-dimensional Euclidean space. Let name this space $\varepsilon(2)$.
When the supplying voltage u is periodic sinusoidal and $L = 0$ and also $C = 0$ the *RLC* system consumes the full energy:

(1.1.3) $E_S = E_P$

because the reactive components *L* and *C* consumes not any energy. Here is trivial clear that the active component of energy E_P constitutes a one-dimensional Euclidean space. Let name this space $\varepsilon(1)$.

When the supplying voltage u is continued and $L = 0$ and also $C = 0$ the *RLC* system consumes the full energy as in the case defined in the equation (1.1.3). Here also the active component of energy E_P constitutes a one-dimensional Euclidean space named $\varepsilon(1)$.
The full energy E_S presents the scalar production:

(1.2) $$E_S = \int_0^t IUdt = UIt = St,$$

Where I and U are effective values of the current i trough the system and the input voltage u, S – full consumed power that also possess three components: P – active, Q – reactive and D – deforming.
The integral (1.2) is convergent in the sense of Lebesgue that means an integral of Riemann because the current i and the voltage u are limited function of an absolute and calendar time t, that make them one-signed and reversing. So they are integrated after a raise to the second power and by this cause the effective values I and U represents norms (magnitudes) of the vectors $i(t)$ and $u(t)$ in the space L^2.
Axiom A1.4. The concept **effective value** is a physical measure for energetic effectiveness of **action** or **quality** of the system.
Axiom A1.5. The consumed by the system full energy E_S is a monotonous function of the time t.
If the *RLC* system is switched on network with practical infinite power and besides the input voltage u - the quality of the energetic flow – and the parameters R, L and C are constant trough all working period of the system, about definition **D1.2** it is **invariant.**

2. Transitive energetic mode in *RLC* system

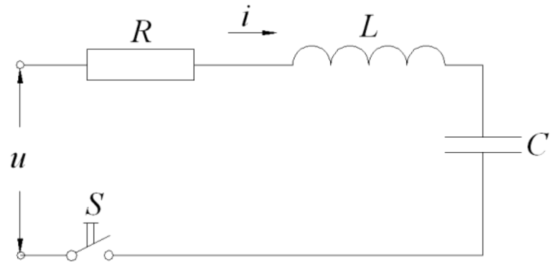

Figure 1.4. System *RLC* in transitive mode

Definition D1.6. The invariant system is in state of transitive working mode when its action (in this case – the current) pass from one stable value to other also stable.
In the case on figure 1.4 the transition of the system is reduced from switched off state to switched on of the switch S. The input voltage u begins to supply the system from zero to some stable value $u(t)$. After some delay trough the circuit will pass the current $i(0)$, that will strive to provoke the voltage fall $u(0)$, balancing the input voltage u.
According the equation of Parseval the energy $E(0)$ consumed by the *RLC* system trough the time of transition will be:

(1.3) $$E(0) = \int_{-\infty}^{\infty} u(0)i(0)dt = \int_{-\infty}^{\infty} \overline{u(\Omega)}i(\Omega)d\Omega, \ \Omega \in R.$$

Here the voltage fall $u(0)$ presents the vector sum by active, inductive and capacitive falls in the *RLC* circuit about the equation:

(1.4) $$u(0) = u_R(0) + u_L(0) + u_C(0)$$

And the symbols $i(\Omega)$ and $u(\Omega)$ in the equation (1.3) presents:

(1.5) $$i(\Omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} i(0)e^{-j\Omega t}dt$$ and

(1.6) $$u(\Omega) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\infty} u(0)e^{-j\Omega t}dt$$

the Fourier pictures of the transitive current $i(0)$ and the transitive voltage fall $u(0)$ in the *RLC* circuit.

By the reverse Fourier transformation, the functions $i(0)$ and $u(0)$ will have in the time *t* description:

(1.7) $i(0)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} i(\Omega)e^{j\Omega t}d\Omega$ and

(1.8) $u(0)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} u(\Omega)e^{j\Omega t}d\Omega$.

According equation (1.1) the voltage falls (the voltages) $u_R(0)$, $u_L(0)$ и $u_C(0)$ will be

(1.9) $u_R(0)=Ri(0)$ or

$$u_R(0)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} Ri(\Omega)e^{j\Omega t}d\Omega,$$

(1.10) $u_L(0)=L\frac{di(0)}{dt}$ or

$$u_L(0)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} j\Omega L i(\Omega)e^{j\Omega t}d\Omega,$$

(1.11) $u_C(0)=\frac{1}{C}\int i(0)dt$ or.

$$u_C(0)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} \frac{1}{j\Omega C} i(\Omega)e^{j\Omega t}d\Omega$$

The Fourier pictures or frequency spectrums $u_R(\Omega)$, $u_L(\Omega)$ and $u_C(\Omega)$ of the transitive voltages $u_R(0)$, $u_L(0)$ and $u_C(0)$ will be:

(1.12) $u_R(\Omega)=Ri(\Omega)$,

(1.13) $u_L(\Omega)=j\Omega L i(\Omega)$ and

(1.14) $u_C(\Omega)=\frac{1}{j\Omega C}i(\Omega)$.

According the logics of the equations (1.12), (1.13) and (1.14) the argument of the current spectrum defines the dependencies:

(1.14.1) $\arg[u_R(\Omega)]=\arg[i(\Omega)]$,

(1.14.2) $\arg[u_L(\Omega)]=\arg[i(\Omega)]+\pi/2$,

(1.14.3) $\arg[u_C(\Omega)]=\arg[i(\Omega)]-\pi/2$

Follow the Parceval logics of equation (1.3) consumed active and transitive energy $E(0)_R$ will be:

(1.15) $E(0)_R=\int_{-\infty}^{\infty} Ri(\Omega)^2 d\Omega$

Respectively the inductive transitive energy $E(0)_L$ will be:

(1.16) $E(0)_L=\int_{-\infty}^{\infty} j\Omega L i(\Omega)^2 d\Omega$ and

The capacitive transitive energy $E(0)_C$:

(1.17) $E(0)_C=\int_{-\infty}^{\infty} \frac{1}{j\Omega C} i(\Omega)^2 d\Omega$.

The three energies from the equations (1.15), (1.16) and (1.17) are in phase with the voltages from the equations (1.12), (1.13) and (1.14) and they are phased one toward other according the equations (1.14.1), (1.14.2) and (1.14.3) and

Invariants	Full energy $E(0)_S$	Algebraic structure (energetic space)
R≠0, *L*≠0, *C*≠0	$E(0)_S = \sqrt{E(0)_R{}^2 + [E(0)_L - E(0)_C]^2}$	$\varepsilon(2)$
R≠0, *L*=0	$E(0)_S = \sqrt{E(0)_R{}^2 + E(0)_C]^2}$	$\varepsilon(2)$
R≠0, *C*=0	$E(0)_S = \sqrt{E(0)_R{}^2 + E(0)_L]^2}$	$\varepsilon(2)$
R≠0, *L*=0, *C*=0	$E(0)_S = E(0)_R$	$\varepsilon(1)$
R≠0, *L*≠0, *C*≠0, in resonance	$E(0)_S = E(0)_R$	$\varepsilon(1)$

Table 1. Description and algebraic structure of the full transitive energy $E(0)_S$

because of this fact the full transitive energy is subordinate to the regularity:

(1.18) $E(0)_S = \sqrt{E(0)_R^2 + E(0)_X^2}$, where

(1.19) $E(0)_X = E(0)_L - E(0)_C$

Dependency on the number and the correlation between the invariants in the system the consumed full energy $E(0)_S$ will have description and algebraic structure according the table 1 (see above).

Theorem T1.2. For preserving of invariant state of every system in stable and transitive mode it is necessary the energetic space $\varepsilon(i)_G$ of its supplying source *ES* (see the figure 1.1) and the energetic space of its object *O* $\varepsilon(j)_C$ to be contra variant and with equal dimension or:

(1.20) $E_{SG} + E_{SC} = 0$ and

$E(0)_{SG} + E(0)_{SC} = 0$, as and

(1.21) $\dim \varepsilon(i)_G = \dim \varepsilon(j)_C$ or *i* = *j*.

Proof: According the equations (1.1) and (1.4) the supplying voltages *u* and $u(0)$ of the system *RLC* must be in contra phase with the stable and transitive falls in the system. But it is possible when is available the condition (1.20). On the other hand, the condition (1.20) is possible then and then only when is available the condition (1.21).

3. Flowing transition of the output value between two stable states.

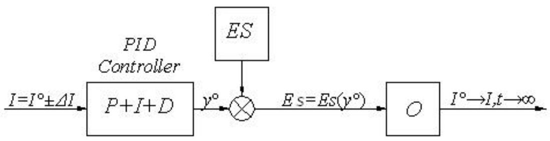

Figure 1.5. Open controlled system

Definition D1.7. System (see figure 1.5) without a reverse connection (loop) between its output value with its entry value is named **open** or **open controlled.**

Theorem T1.3. For preservation of the invariant state of every system it is sufficiently the energetic flow E_S to the object *O* (see figure 1.1) to be controlled by a **proportional integral and differential controller** or ***PID* controller**.

Proof: As shows its name the *PID* controller is tuned so that its proportional or *P*-part controls active transitive energy $E(0)_R$ to the object, its integral or *I*-part – capacitive transitive energy $E(0)_C$ and its differential part or *D*-part – inductive transitive energy $E(0)_L$. The three parts of the controller are tuned according the magnitude of every mode of energy. Three parts of the controller are tuned according the momentary value of the respective mode of energy, that responds to relevant mode of nominal power. If the input current must be changed to the value:

(1.22) $I = I^0 \pm \Delta I$,

the controller will compose to its output the function:

(1.23) $$y^0 = k_P I + T_D \frac{dI}{dt} + \frac{1}{T_I}\int_0^t I dt,$$

where k_P is a constant of proportionality corresponding of the resistance *R* in the *RLC* system, T_D - constant of differentiation corresponding of the inductivity *L* and T_I - constant of integration corresponding of the capacity *C*. The function y^0 will increase or decrease the energetic flow (full energy) E_S to the object *O* so that it will be changed in the function:

(1.24) $$E_S = E_S(y^0)$$

So, will be saved the conditions (1.20) and (1.21) of the theorem T1.2 and the beginning value of the current I^0 will reach invariant in the time *t* to the value *I*.

Theorem is proved.

And with that was presented and proved the conditions by that is possible to mould an electric system in invariant mode.

There was accepted that is not permissible the concept **system** to be examined from a material abstract viewpoint, because the engineering practice don't permit that. By **system** in the future there will understand only **energetic system.**

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