

## FROM ELECTRICA TO INVARIANT AUTOMATICA

### (Or how to use the knowledge about Theory of Electricity for enter into Theory of Invariant Automatic Control)

Milan M. Stankov

Graduated from TU-Sofia in 1967, major: Electrical Installations and Industrial Automatics, Bulgaria

**\*Corresponding author**

Milan M. Stankov, Graduated from TU-Sofia in 1967, major: Electrical Installations and Industrial Automatics, Bulgaria.

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#### PART ONE. SYSTEM AND INVARIANT ELECTRIC MODEL

##### Energy and System

The knowledge of Theory of Electricity as a rule serves for a common view over all educatives themes that contain the concept electricity, regardless of its applications in machines, installations, equipments, communications etc. The investigation the properties of the electricity like a mode of the matter, it becomes evident the behaviors of the electromagnetic field in the space and the time, of the electric current in conductors and semiconductors, of the electric energy in the transferring and distributing systems as and its consumption in machines, installations, equipments, towns and cities etc. But furthermore, in the fields when the electric energy is unavoidable necessity, there is possible the theoretical knowledge about the electricity to serve also for moulding of every kind of system, independently of the nature of the energy (mechanical, thermal, chemical, thermonuclear, etc.). That follows from the concept “energy” coming from the

**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

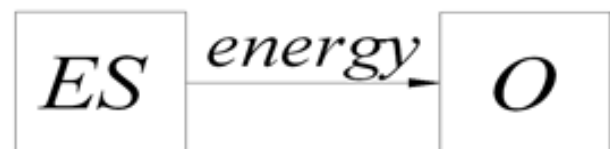
Like a consequence from theorem T1.1 cannot renounce that the state of energetic of every human community (state, union, empire etc.) defines qualitatively and quantitatively the existence of its civilization. And in view of the fact that the characterization of every community requires a systematic method of approach, it is necessary to define the concept system.

**Definition D1.1.** System is every pair from the description of fig-

ure 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.).



**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 through 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.

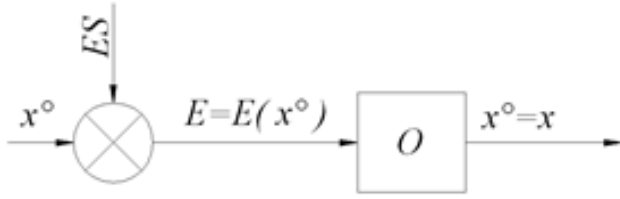


Figure 1.2

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**.

### System RLC like a model of invariant system.

1. Balanced (stable, permanent, continued) energetic process in a RLC system.

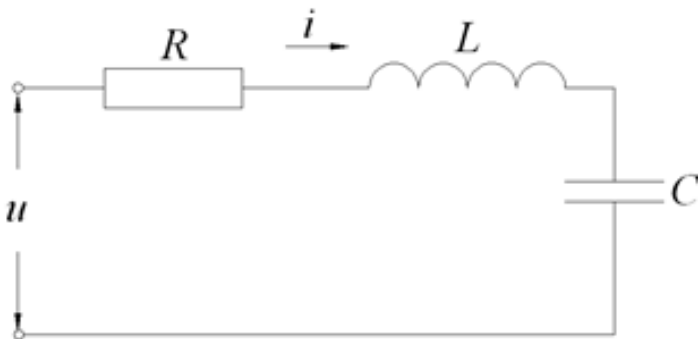


Figure: 1.3. System Rlc In Stable Mode

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:

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

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 is periodic the RLC system consumes the full energy:

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

$E_P$  is active,  $E_Q$  – reactive and  $E_D$  – deforming component of energy. The three components constitute a tridimensional Euclidean space. Let name this space  $\epsilon(3)$

When the supplying voltage  $u$  is periodic sinusoidal the RLC system consumes the full energy:

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

Here the deforming component  $ED = 0$  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  $\epsilon(2)$ .

When the supplying voltage  $u$  is periodic sinusoidal and  $L = 0$  and also  $C = 0$  the RLC system consumes the full energy:

$$(1.1.3) \quad E_S = E_P$$

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

When the supplying voltage 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  $\epsilon(1)$ .

The full energy presents the scalar production:

$$(1.2) \quad E_S = \int_0^t IU dt = UI t = St,$$

Where  $I$  and  $U$  are effective values of the current 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 and the voltage 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 – 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

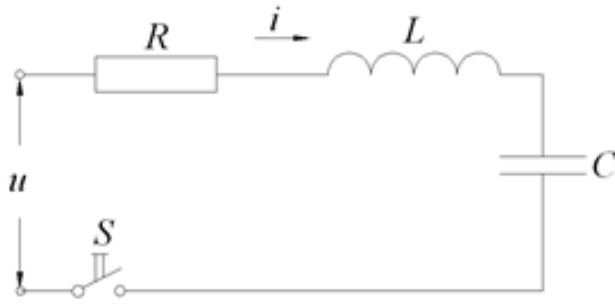


Figure: 1.4: System Rlc In Transitive Mode

**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, that will strive to provoke the voltage fall  $u(0)$ , balancing the input voltage  $u$ .

According the equation of Parseval the energy consumed by the RLC system trough the time of transition will be:

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

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

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

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

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

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

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:

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

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

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

$$(1.9) \quad u_R(0) = Ri(0) \text{ or}$$

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

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

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

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

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

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:

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

$$(1.13) \quad u_L(\Omega) = j\Omega Li(\Omega) \text{ and}$$

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

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

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

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

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

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

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

Respectively the inductive transitive energy will be:

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

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

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

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

**Table 1: Description and Algebraic Structure of The Full Transitive Energy  $E(0)_s$**

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

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

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

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

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:

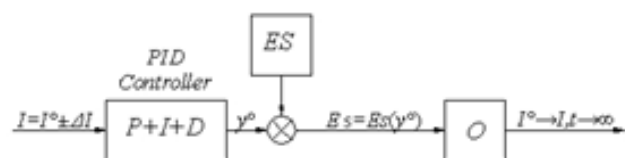
$$(1.20) E_{SG} + E_{SC} = 0 \text{ and}$$

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

$$(1.21) \dim \varepsilon(i)_G = \dim \varepsilon(j)_C \text{ or } i = j.$$

**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).

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 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:

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

where  $k_p$  is a constant of proportionality corresponding of the resistance  $R$  in the RLC system, - 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) 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**, because the concept **energy** is an universal measure for existence of the matter and, conse-

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quently, for existence of any aspect of system. That will become visible in the second part of this article.

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