AN INVESTIGATION OF MULTI-DOMAIN ENERGY DYNAMICS

A Dissertation

by

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ABSTRACT

This research investigates common patterns in all energy systems to develop insights and a clearer understanding of energy conversion and transmissions. The potential benefits of this research are to introduce conceptual models of power conversions that can suggest new power conversion machines, understand some known physical laws, and propose new laws of energy dynamics.

The electromagnetic domain is used as an archetype domain since it is the most completely developed and well-documented domain. In this research, an extensive study for the electromagnetic domain and the comparisons between other domains are presented. The work is based on the fact that in all energy engineering systems, the variables to transmit power are similar in functionality. Power can only exist when energy transfers and mutates in space. However, moving in space requires flow, and that flow cannot happen without effort. This work also presents the importance of power conversion through media.

In order to connect all energy systems together, some variables should be defined in all existing energy systems. Some of these variables are defined in the literature, such as electrical, but the others are not, such as the thermal and magnetic systems.

A comparison between the new approach and the other existing models is presented in order to highlight the differences between the conventional and proposed

one. Finally, theoretical verifications and explanations of some concepts are presented in this research in a better and more powerful way to validate our theory.

DEDICATION

To my family

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1 INTRODUCTION

1.1 Overview

Energy dynamics represents the behavior of energy, power, and properties of macroscopic energy systems. A global classification of energy variables for all domains, based on their physical and conceptual behavior, is very important for revealing analogies and distinctions between various energy systems. In addition, it helps to establish a mathematical model that includes the sets of differential equations between the energy system itself and other systems. These mathematical equations represent the description of energy behavior for some or all physical observations [1, 2].

Each energy system has different variables that identify its behavior. For example, the most commonly used variables in electrical systems are voltage and current. In mechanical systems, the most commonly used variables are force and velocity. In fluid systems, the most commonly used variables are pressure and volumetric flow rate. All these variables, regardless of what energy system is being used, produce power. In other words, in all energy systems, the variables necessary to calculate power are the same in functionality: an effort needed to create a movement in a fluent, and a flow or rate at which the fluent moves. Therefore, the power equation can be generalized as a function of these two parameters: effort and flow [3].

$$\text{Power} = \text{Flow} \times \text{Effort}. \tag{1}$$

Analyzing various power transfer media for interconnected energy systems requires identifying effort quantity, the flow quantity, and three passive elements used to establish the amount of energy that is stored or dissipated as heat [2].

1.2 Energy

Energy plays a key role in the development of physics and all branches of science. The interpretation of energy transformation from one place to another, and the interpretation of energy transformation from one form to another are very important. The impact of the concept of energy on society has been enormous on the logical and technological aspects [4, 5].

The modern scientific concept of energy is fairly new. For example, in the late 1600s, Christiaan Huygens realized for the first time that when objects collide, force is transferred among them[6]. In 1743, energy had spatial name “vis viva”, which is related what is currently called kinetic energy or force living that has been formulated by D’Alemeert to be the effective force measured by its effect over time[7]. Mathematically,

$$\int_{to}^{t1} \mathrm{F\,dt} = (\mathrm{mv_1} - \mathrm{mv_2}), \qquad (2)$$

where F is the force, m is mass, and v is the velocity.

On the other hand, he said that it is possible to measure the effective force by its effect over space and that can be represented by the following equation [7]

$$\int_{xo}^{x1} F\,dx = (\frac{1}{2}mv_f{}^2 - \frac{1}{2}mv_i{}^2). \quad (3)$$

In other words, the accumulative effect of force over distance is equal to the change in the quantity $0.5mv^2$ between x_1 and x_0.

In 1798, Benjamin Thompson proved that heat was also a form of energy. In the early 1800s, James Prescott Joule studied how motion changed into heat and realized that any form of energy could be changed into any other form[8].

Hermann von Helmholtz wrote the law of conservation of energy in its final form in 1847 [9]. In the early 1900s, Albert Einstein showed that mass can be transformed into energy and discovered that high levels of energy can add to an object's mass[10].

The concept of energy is still rather abstract, obscure, and mysterious, and in the past four hundred years, the notion of energy has not become deeper or more concrete[11-13]. Here is how one of the greatest physicists of the 20th century described his understanding of energy in his lectures at Cal Tech. University: "So far as we know there are no real units of energy. It is abstract, purely mathematical. There is a number such that whenever you calculate it, it does not change. I cannot interpret it any better than that[14]."

1.2.1 Origins of Energy

Energy conversions in the universe over time are characterized by different types of "potential energy" that have been available since the Big Bang. All stellar phenomena are driven by different types of energy conversions (energy transformations). The energy in those transformations is either in the form of gravitational collapse of matter or nuclear fusion[15-17].

1.2.2 Conservation of Energy

The discussion of conservation of energy can be easily understood when talking about the conservation of mechanical energy. We know when we consider a single conservative force doing work on closed system; the work done by the conservative force is defined as the change of kinetic energy. Also we know that the work done by conservative force will be the opposite change of the potential energy. In other words, the change of kinetic energy will be opposite the change of potential energy[7].

$$(\Delta K = -\Delta U) \rightarrow \ \Delta K + \Delta U = 0. \tag{4}$$

The sum of kinetic and potential energy, also known by mechanical energy, is constant for a closed system. If there are only conservative forces, the initial energy is then equal to the final energy. This is called the conservation of mechanical energy.

$$K_i + U_i = K_f + U_f. \tag{5}$$

Non-conservative forces change the total mechanical energy of a system, but not the total energy of a system since energy cannot be created or destroyed. Work done by non-conservative force is typically converted to internal (thermal energy) which becomes to the change of temperature of the system. Therefore, the total energy is equal to the kinetic energy and the potential energy and any work done by non-conservative forces.

$$W_{tot} = K + U + W_{non}. \tag{6}$$

1.2.3 Forms of Energy

Energy manifests itself in various forms: mechanical energy, thermal energy, chemical energy, electrical energy, radiant energy, nuclear energy, and planetary energy [18].

Mechanical energy can be defined as a form of energy that can be used directly to do work. Two forms of mechanical energy: potential energy and kinetic energy.

Potential energy is defined as energy stored on an object due to an elastic distortion. For example, when we are looking at "stretched bow and water reservoir", we get impression that this kind of object does not possess energy. But we know that the arrow moves when a stretched bow is released, and the water wheel starts moving when the stored water fills the water wheel. In other words, the stretched bow and water reservoir store energy due to their positions and conditions. Thus, potential energy (Gravitational potential energy) can be defined as the energy possessed by a body by virtue of its position or condition. The formula to calculate the potential energy is defined by $W_p = mgh$, mass of the object, g is accelerating of gravity and h the high of the object [19].

Kinetic energy is energy possessed by an object due to its movement. For example, an object moves by moving water in a river. Moving water is able to do work as it possesses energy [7].

$$W_p = \frac{1}{2}mv^2. \tag{7}$$

Potential energy and kinetic energy are two forms of mechanical energy and they can be converted from one form to another.

Thermal energy is a specific type of kinetic energy and is associated with the microscopic random motion of particles. It is the sum of latent forms of internal energy. It is related to the degree of molecular activity and the molecular structure. Thermal energy and temperature are different. Thermal energy represents the total amount of kinetic energy in a sample of matter. Temperature is defined as the average amount of kinetic energy in a sample of matter. All matters in earth contain energy. There is energy in atmospheric gases and even in grains of salts. Matter is made up of atoms and molecules. Molecules inside matter are in a constant motion and have internal energy, which is called thermal energy. Heat energy can be converted to another form of energy and other forms of energy can also be converted to heat energy[20-22].

The energy we use to run our cars and our bodies is chemical energy. Chemical energy is defined as the energy stored in the bonds of molecules and chemical compounds. It is the potential of a chemical substance to undergo a transformation through a chemical reaction. We are going to explore the energy in chemical bond using the formation of water from hydrogen and oxygen gas. Start by looking at some other components of reaction[23]

$$2H_2 + O_2 = 2H_2O. \qquad (8)$$

Hydrogen gas combines two hydrogen atoms held together by a single covalence bond. Energy is released when the covalent bond is formed between these hydrogen atoms. The same is applied for other molecules (oxygen gas). What happens is bonds holding molecules together are broken the atoms in molecules are then rearranged and therefore new bonds are formed and this is the general process for all chemical reactions[24].

Electrical energy is defined as the energy associated with the presence and flow of electric charge. It described by two types [7].

Electrostatic: It is defined as energy of electrically charged particles in an electric field.

Electro-dynamic or magnetic energy: potential energy stored in the magnetic field associated with electric current, or movement of charged particles.

Radiant energy is defined as the energy created through electromagnetic waves, such as light, heat, or radio waves[25] .

Nuclear energy is defined as the energy released by the splitting or merging together the nuclei of atoms. Nuclear energy is released by three exothermic processes: Radioactive decay, Fusion, and Fission [26, 27].

Radioactive decay is the process that occurs when a nucleus of an unstable atom loses energy by emitting particles of ionizing radiation.

Fusion and fission of nuclear physics turn matter and energy using the most famous equation in all science: $E = mc^2$. The equation tells us that the matter can turn in energy and when it does, it gets multiplied by the speed of light squared, which is a very big number. Both fusion and fission convert a little bit of matter into a lot of energy. Fission means to come apart and fusion happens when atoms come together (when two become one). In both cases, we end up with a little less mass than we started with. That missing mass is multiplied by squared of light to become energy [28].

Planetary or gravitational energy is defined as the potential energy associated with gravitational force. Height relative to some reference point, strength of the gravitational field, and mass are the factors that affect an object's gravitational potential energy [7].

1.2.4 Energy Conversion

Energy conversion process is the process of changing form to provide some services under the conservation of energy. Transducer is a device that converts energy from one form to another. For example, in diesel engines heat energy is converted into mechanical energy. In a generator, mechanical energy is converted into electrical energy. In an electric fan, electrical energy is converted into mechanical energy. Currently we have many devices that have been invented due to the energy conversion process, such as batteries, televisions, DC motors, etc.

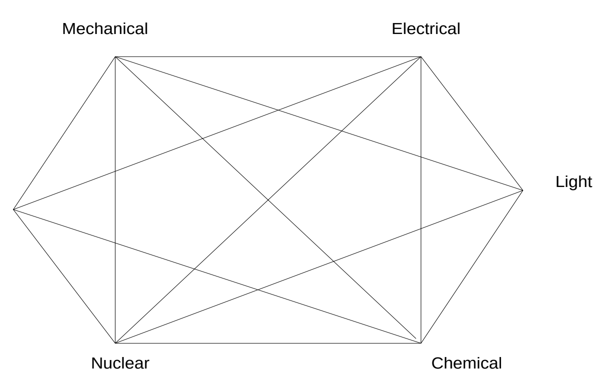

Fig.1 Energy conversion between different energy systems

Fig.1 shows some possible energy conversions in machines. For example, chemical energy in the coal is converted to thermal energy. Mechanical energy of the turbine is converted to electrical energy. Chemical energy conversion is converted to kinetic energy for piston movement purposes.

1.2.5 What is Energy?

Energy is an abstract quantity, an attribute, or a property of matter that cannot be seen or touched like material objects. The simplest dimensions of energy, as given in the present physics books, are (ML^2T^{-3}). “It is a “quantity” that can be assigned to every particle, object and system of objects as a consequence of the state of that particle, object or system of objects” [29]. Energy is matter changed to a different form. Yet another definition of energy is the ability to do work.

Energy is something that has several mysterious properties. For example, when two objects hit together, nothing transfers, the velocity of the high object slows down and the second object’s velocity goes up. When you make a sound, molecules of the air agitate and move the sound, without moving mass. In this theme, three different levels of the energy concept will be introduced [30].

At the elementary level, energy is defined as the ability to do work. This is an abstract definition as the ability and work are not defined properly. For example, what do we mean by ability? How can we define it?

$$\text{Energy} = Force \times distance, \tag{9}$$

where force is something that accelerates mass, which is also defined as $\mathrm{F} = \mathrm{ma}$.

At the intermediate level, energy and mass are equivalent. In other words, mass can be converted to energy and energy can be converted to mass, through the most famous energy equation.

$$\mathrm{E} = m \times c^2, \tag{10}$$

Where m is mass and c is the speed of light.

From (9) and (10), we can conclude that a small amount of mass can produce numerous amounts of energy, meaning that the mass is no longer constant. Another definition of energy comes from Planck law and quantum mechanics that is related to the quantum frequency though the following equation

$$\mathrm{E} = h \times f. \tag{11}$$

From (11), energy and time seem to be linked though the plank's constant.

At the advanced level, energy is conserved because it is time invariant. Energy variables change their properties and change their kinetic and potential energy, but the total energy is always conserved. This is the most accurate definition of energy, since it shows that the old or the classical energy concepts are not conserved because the mass energy is missing in their equations.

1.3 Thermodynamics

The term Thermodynamic is derived from the Greek which means dynamic force. The scope of thermodynamic study was only restricted to study of heat transfer and heat nature. The pioneers who established this science were Sadi Carnot, Robert Mayer, Hermann Helmholtz, and Rudolf Clausius [21, 22].

In about 500 BC, Heraclitus classified fire as an independent element of nature in addition to other three elements, namely water, earth, and gas. In 300BC, Zhou Yan claimed that the physical universe has five nature elements namely metal, wood, water, fire, and earth. In the 18th century, the steam engine that relates work to heat was introduced. In 1798, Count Rumford observed that the heat and work done are directly proportional. In 1824, Sadi Carnot proposed Carnot theorem that made a foundation for a new discipline of thermodynamics, which was entirely different from the classical ones. In his theorem, he discovered that the only way to perform work in steam and heat engines is to transfer heat from hot reservoir (which is called heat source) to the sink source. In 1798, Benjamin Thompson proved that heat was also a form of energy. In the early 1800s, James Prescott Joule studied how motion changed into heat and realized that any form of energy could be changed into any other form. Hermann von Helmholtz wrote the law of conservation of energy in its final form in 1847 [8, 21, 31].

1.3.1 Laws of Thermodynamics

The section investigates the heat transfer, temperature, equilibrium, and thermodynamics through discussing the laws of thermodynamic and its processes.

Thermal equilibrium is defined where the temperature does not seem to change. Temperature and thermal equilibrium represent macroscopic properties and they are not always defined. For example, suppose there is a gas inside a piston and some weights and everything is in equilibrium. The system in this case is equilibrium because the macroscopic things, nothing is changing. But, if some of the weights are removed, the piston's going to rise up, shake around a little and settle down in a new location and then goes back to the initial state. Whenever a system is in such equilibrium, it can be assigned to a temperature T. The concept of temperature is defined through one of the laws of thermodynamics, which is called the zeroth law of thermodynamics [21, 32, 33].

The zeroth law of thermodynamics states that "if two thermodynamic systems are each in thermal equilibrium with a third, then all three are in thermal equilibrium with each other" [29].

First law of thermodynamics is generally referred to as the conservation of energy, which means that energy can neither be created nor destroyed, but it can change forms. In other words, the total amount of energy in a closed system remains constant. They are several ways to express mathematically the first law of thermodynamics,

$$\sum \Delta E = 0, \tag{12}$$

which means that the total change in energy form 1 and change in energy form 2 is equal to zero.

$$\Delta E_1 + \Delta E_2 = 0. \tag{13}$$

The significance of the first law of thermodynamics is that the total amount of energy in the universe is constant, so it is impossible to get more energy than it is put into a system. Simply, energy cannot be generated from nothing.

The second law of thermodynamics deals with thermal equilibrium. In its simplest form, this law states that heat always flows from hot to cold. We can make energy flow from hot to cold, but in nature spontaneously that will never happen. This applies to every object in the universe. Heat moves to make a constant temperature. So the universe is ultimately approaching a constant temperature [34].

The second law of thermodynamics is based on the observation that the heat cannot go from cold to hot. This suggests that there is a law that would forbid it. To better explain the concept of the second law of thermodynamics; let us discuss the first heat engine that uses heat transfer to do work by converting heat energy into mechanical energy. Basically, the globe of the top is filled with a liquid that is heated to produce steam. We know the steam expands and causes the whole apparatus to rotate [21].

The second law of thermodynamics states that no process is possible whose sole result is the complete conversation of heat from a hot reservoir into mechanical work. In other words, you cannot attain 100% efficiency. From the first law of thermodynamics we know that the energy difference in a system is equal to the amount of heat (Q) and the amount of work (W) [21].

$$\Delta u = Q + W. \tag{14}$$

But the second law of thermodynamics says that you cannot modify the equation above.

$$\Delta u \neq Q + W. \tag{15}$$

Heat engine has a reservoir, which is called heat source at the high temperature and heat sink at a low temperature. Between the reservoirs there is an engine. The heat engine takes heat from the heat source and it does something with it (it may get some work out) and whatever cannot be converted into work gets to the heat sink (you can think of it as waste heat). If we have 100% efficiency, this means that Q_H is equal to work. However, the second law of thermodynamics says that there is always heat loss affects the efficiency and that explains (15).

Entropy is thermodynamics' property; it represents the disorder or random less of the system and always increases never decreases as time goes on. The entropy of the universe is increasing and will lead to what is affectionately known as "heat death of the universe"[21]. Boltzmann formulated the number of states in which energy can be stored.

$$S = kB. \sum p_i \log(p_i). \tag{16}$$

where S is entropy, kB is the Boltzmann constant, equal to 1.38×10^{-23} $J{T_\theta}^{-1}$, and p_i the probability that the systems is in the i^{th} states.

Third law of thermodynamics states when the temperature of a substance approaches absolute zero, the entropy of a substance also approaches zero. Water vapor has molecules that can move around and has very high entropy. The water vapor has molecules that are far apart from each other and they can move freely. The water vapor has high entropy, since they are randomly distributed and move and therefore causes high entropy. As gas cools down, it becomes a liquid, whose molecules are still move around but not as freely as before. They have lost some entropy. As the temperature of a substance approaches absolute zero, the entropy approaches zero [21].

1.3.2 Thermodynamic Process

A thermodynamic process represents the changing of the system state variables and does have a well-defined start and end points as shown in Fig. 2.

Fig. 2 shows four processes in pressure-volume states. Process 1 and 3 are called isothermal process, whereas processes 2 and 4 are isochoric process [35].

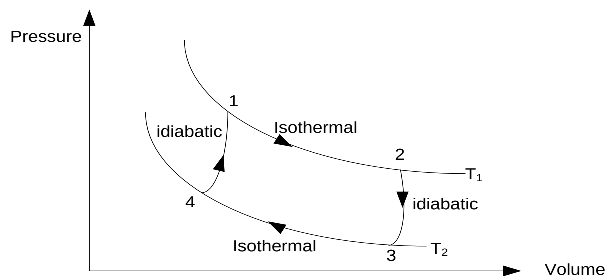

Fig. 2 Carnot cycle process

The pressure and volume are energy variables for any hydraulic system and represent the amount of work produced during the transfer of mechanical or dynamic energy. An isobaric process is a process at which the pressure difference is zero. The pressure does not change during the process. An isobaric process is a process at which the volume difference is zero. The volume does not change during the process [35].

The temperature-entropy represents how much thermal energy is being transferred as the result of heating. An isothermal process is a process that occurs at a constant temperature. An adiabatic process is a process where no energy added or subtracted from the system by heating or cooling [35].

1.3.3 Limitations and Problems with the Current Theory

Thermodynamics is a powerful tool for solving problems related to heat transfer and entropy changes. It is based on observations that are extracted from some laws that explain some phenomenon. However, these laws cannot be proven and cannot explain and answer some specific phenomena or questions. For example, thermodynamics can predict some processes, but it cannot tell us how fast that process occurs. Yet it can only provide a quantitative description of an overall change in state without going further. Furthermore, thermodynamics only applies to macroscopic systems and does not give deep insights into mechanical and physical phenomena at a microscopic level[36].

Some papers discussed the thermal inductance within two different domains. The paper in [37] sets up an experiment, in which a wire exists in a volume of a fluid. At a given time $t = 0$, a current is passed through the wire, which makes the wire a source of heat flow that has now gone through a positive step change. This source of heat flow can be modeled as a current source in an equivalent thermal circuit. As the authors explain, at first the flow of this heat out into the fluid to the eventual ambient only occurs through thermal conduction, and that process has a relatively large thermal resistance. Eventually, however, thermal convection cells form that lower the overall thermal resistance, but that takes time due to the inertia of the fluid. Also, the fluid has an overall thermal capacity.

The authors in [37] argue that this phenomenon of going from a high thermal resistance to an alternate path having a lower thermal resistance over time is properly modeled as a large resistor in parallel with a smaller resistor, the latter having an inductor in series with it. The combined circuit is then placed in parallel with a thermal capacitor. If the circuit elements are such that the damping is not too high, the wire temperature (the voltage in the equivalent thermal circuit) will go higher than its eventual value and return to its final value with a decaying oscillation.

The definition of the thermal inductor would be a device that stores energy within it due to the flow of heat energy through it. The convection cells do that by storing the kinetic energy of the moving fluid.

Note, however, that if the current is turned off in the wire, we cannot get the wire temperature to drop below the ambient temperature, whereas in the thermal circuit if we made the current source step back to zero the voltage across the source would momentarily ring negative. So there is a clamping action that must be accounted for.

But, if the wire's current is stepped from I_o to $2I_o$ and back again, then the wire temperature can overshoot the final temperature associated with $2I_o$ before settling in, and the wire temperature can undershoot the final temperature associated with I_o before settling in (as long as that undershoot does not go below the ambient temperature). In this incremental sense (when the experiment has an offset with regard to zero heat flow) the convection cells behave like an inductor in all ways.

In short, the inductance behavior only observes in the convection process. In other words, the inductance cannot exist solely in the thermal process by itself due to the second law of thermodynamics [38]. In this dissertation, we will show that the thermal inductance can exist in the thermal system without contradicting the second law of thermodynamics, due to the fact that thermodynamics is only valid in the steady state not in the transient state.

The model in [39, 40] shows that temperature (T) is analogous to voltage, and heat flow $\dot{Q}$ is analogous to current. By applying the Ohm's law, thermal resistance $R_{th} = \frac{T}{\dot{Q}}$, it can be concluded than the dimension of thermal power is not correct. The author in [39] classified the thermal system as an auxiliary system (not real energy system), and therefore the energy universality cannot be applied to this system.

In an effort to correct some of these statements, we have proposed a different model that is consistent with energy universality. The proposed model is based on the energy patterns in electrical systems.

1.4 Dissertation Plans

My dissertation is organized as follows:

1. A brief idea of propositional energy dynamic theory
2. Investigation of energy patterns in all energy systems
3. Case studies for the proposed theory

1.5 Research's Contributions

1. A coherent theory of a power conversion in all energy domains
2. New conceptual models of power conversion machines
3. Mathematical differential equations for energy dynamic theory

2 LITERATURE REVIEW

2.1 Bond Graph and Interconnect Systems

The idea of trying to model an energy flow in various media has been attempted by other researchers; the most famous model is "Bond Graph", which was invented by Poyinter, a professor from MIT University. Bond graph represents a graphical connection of a physical dynamic system [41]. Poyinter introduced the general concept of effort and flow in all energy media. However, his theory does not explain some physical concepts, like the concept of magnetic resistance. Furthermore, the reluctance model (reluctance stores energy rather than dissipating energy) and thermal model are inconsistent with energy universality [42, 43]. The analogy between various energy systems will be discussed in the next sections.

2.1.1 Electrical System

In electrical systems, the free charge (q_e) is generally the conserved quantity. However, in dielectric materials, due to the tight atom-electron bonds, there are no free charges. The electric phenomenon is the result of the interaction of electric fields and the polarized charges of the dielectric material. These charges, which are basically electric dipoles, are known as bound charges to distinguish them from the free charges [42] .

In electrical systems, the effort quantity is most commonly known as voltage (V), electric potential (U_e) or electromotive force (emf). It is the force needed to move a charged particle from one point to another while in the presence of an electric field. In other words, it is the force needed to generate the flow of current [42]. Mathematically,

$$emf = veB - veA = -\int \vec{E}.d\vec{l}, \tag{17}$$

where E is the electric field and dl is an element of the path from point A to point B.

Electric currents are divided into two classes: conduction currents and displacement currents. Conduction currents result from the movement of charged particles in a conductive medium. The motion of these particles generates heat; therefore, it is usually associated with energy losses.

Mathematically the electric current is given by,

$$Ie = \frac{\partial q}{\partial t} \text{ [A]} \tag{18}$$

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat due to the flow of current in a material. In other words, a resistance represents a degree of flow that a material allows when an effort is applied[42]. Mathematically, the resistance is defined as

$$\mathrm{R} = \frac{\mathrm{V}}{\mathrm{I}} \tag{19}$$

In electrical systems, the capacitance measures the ability of a body to hold a charge (q_e) due to a given potential (ve). It describes the amount of energy stored in the electric field, which is expressed as,

$$C = \frac{q_e}{V} \tag{20}$$

Similar to the resistance, the capacitance is also a representation of the material. Therefore, its value depends on the intrinsic property of the dielectric and the geometry of the specimen. This is expressed as,

$$C = \frac{\int \vec{D}.d\vec{s}}{\int \vec{E}.d\vec{l}} \tag{21}$$

In electrical systems, the inductance measures the amount of energy stored in the magnetic field due to the flow of electric current (*ie*)[42]. The inductance is expressed as,

$$L_e = \frac{N\varphi}{I_e} \tag{22}$$

2.1.2 Magnetic Systems

As mentioned previously, the magnetic system does not follow the same pattern. In other words, some parameters in magnetic systems have to be defined. The Reluctance Model is the first model developed to represent magnetic circuits.. This model is based on Hopkinson's law, which is analogous to Ohm's law for electric circuits [44].

In electric circuits, Ohm's law is an empirical relation between the electromotive force (emf) or voltage applied across an element and the current (I) flowing through that element. It is expressed as

$$emf = IR, \tag{23}$$

where R is the electric resistance of the material [Ω]. Similarly, for magnetic circuits, Hopkinson's law is an empirical relation between the magnetomotive force (*mmf*) and the magnetic flux (φ), given by

$$mmf = \varphi R', \tag{24}$$

where $R'$is the magnetic reluctance H^{-1}.

When the reluctance model was defined, (24) was considered analogous to (23) in both form and functionality, but it has been well established that reluctance and resistance are different. The main difference between these concepts is that in electric circuits, the resistance is a measure of how much energy can be dissipated as heat while current flows in the material. Meanwhile, in magnetic circuits, the reluctance is a measure of magnetic energy storage rather than being a measure of magnetic energy dissipation.

The reluctance model limits the progress of magnetic circuit theory for many reasons [42, 45]:

1. Failure to recognize that electric and magnetic quantities are dimensionally amenable to identical mathematical treatment
2. The absence of a magnetic impedance concept
3. The erroneous reluctance-resistance analogy
4. The inductance concept
5. The lack of satisfactory energy transuding element to interconnect the electric and magnetic circuits of the inductor

The law of conservation of energy states that energy can neither be created nor destroyed, only transformed. If we analyze the electrical model, for example, there are three quantities that represent the transformation of energy: the resistance, which indicates the energy that is transformed into heat, the capacitance, which indicates the amount of energy stored in the electric field, and the inductance, which indicates the energy that is stored in the magnetic field.

Table 1 shows the analogy between the electrical and magnetic analogy based on the reluctance model.

Table 1 Different Media Analogs

Generalization	**Electrical**	**Magnetic**
Conserved Quantity	Charge [C]	**?**
Flow	Current [A]	Flux[Wb]
Effort	Voltage [V]	MMF [t·A]
Dissipative Element	Resistance [Ω]	Reluctance [H^{-1}]
Storage Element	Capacitance [F]	**?**
Storage Element	Inductance [H]	**?**

In an effort to correct some of these statements, Lupe in [42] proposed a different model that was also based on the analogy between electrical and magnetic quantities. In [42], the flux is analogous to electrical charge, contrary to the reluctance model where flux was analogous to an electric current. Also, a flux rate, magnetic resistance, magnetic inductance and magnetic impedance are introduced, which is true in functionality and can be validated by examining energy relations.

The energy of an electric capacitor can be expressed as a function of the capacitance (*C*) and the voltage (*V*) as

$$E = \frac{1}{2} C V^2 \ [J] \tag{25}$$

Using a similar relation for the magnetic circuit, where energy is a function of the magnetic (C_{mag}) and the magnetomotive force (*mmf*) then,

$$E = \frac{1}{2} C_{mag} \times mmf^2 [J] \tag{26}$$

2.1.3 Mechanical System

The structure of electrical systems includes voltage, current, and power. Power is the displacement of energy from one location in space to another; its dimension is [ML^2T^{-3}][46]. This structure appears (in linear systems) to be everywhere when energy displaces. In all systems, when energy passes through, there is always effort and flow. In a different domain, effort has a physically different appearance, but the dimension of power and energy are the same. However, in this dissertation we will show that the dimension of energy and power are domain dependent.

For mechanical systems, force and velocity are the most common variables and from these variables, power is produced. Some books consider force to be effort, and velocity to be flow, while others consider the flow is the force and effort is the velocity [39]. All these assumptions appear to be valid, since the power is the multiplication of these quantities. The mechanical resistance in the conventional model is friction and its unit is Newton. Mass and the stiffness of a spring are considered to be either capacitance or inductance, depending on the way the effort and flow of mechanical systems are defined. A dissipative element in the mechanical systems is the energy that is not stored in both kinetic and potential energy. The mechanical energy variables are defined as follows [3].

Flow in mechanical systems is velocity; the movement of the particles in space. It is defined as

$$u = \frac{dx}{\partial t}, \tag{27}$$

where x is the distance and u is the velocity.

In mechanical systems, the effort can be defined as the force needed to generate a velocity or as the force needed to produce work.

A dissipative element represents the amount of energy released as heat due to the flow in the medium. When force is applied, mass starts moving and a friction is created.

A friction is one of the types of resistance. However, in this dissertation, a linear mechanical resistance is only considered and is defined as the ratio of force with respect to velocity. Inductance and capacitance are mass and the stiffness of a spring (K), respectively. Table 2 shows the comparison between the electrical and mechanical systems.

Table 2 Analogy between Electrical and Mechanical Systems

Quantities	**Electrical**	**Mechanical**
State Variable	Charge	Distance
Effort	Voltage	Force [N]
Flow	Current	Velocity
Dissipative Element	$Resistor$	Friction
Storage	Inductance/Capacitance	Mass/Stiffness of the spring

In this dissertation, the mechanical system will be revisited in order to show the importance of momentum for energy dynamics processes.

2.1.4 Fluid and Hydraulic Systems

In a similar way to mechanical systems, fluid and hydraulic systems can be modeled in terms of elementary source, storage and dissipative mechanisms.

2.1.5 Thermal Systems

The conventional thermal model does not follow the pattern of the real energy system [39]. Heat transfer occurs in three different ways: conduction, convection, and radiation. The area of interest is the conduction transfer since diffusions and collisions processes between the particles occur due to the temperature different.

Heat is defined as flow properties, and temperature is defined as an effort. These definitions are not consistent with other energy system definitions. However, defining heat as a flow looks more real since the temperature measures the degree of hotness and is related to the quantity of heat (which tends to flow from high to low temperature). The most common thermal model in literature is discussed below.

A thermal system is considered to be the non-real system and is defined as part of kinetic energy. That means that the thermal system does not follow the same pattern, like the magnetic system. For example, thermal inductance is not defined in literature. The concept of flow in the thermal system is heat, which is analogous to the current in electrical systems. This assumption is inconsistent with the general quantities that have been specified for any real energy system. The modeling of a thermal system is completely different and has different mathematical equations that are only applied in the thermal system. The recent modeling for the thermal system is the finite element, not analogue analogy [39].

In a thermal system, heat is the conserved quantity (J). Flow is the rate of change of heat (heat flow). The effort (temperature) is the force needed to create a flow of heat and move heat from a hot reservoir to a cold reservoir. In other words, it is the force needed to generate the flow of heat. A thermal resistance is a heat property that measures the ability of the material to resist a heat flow. A thermal capacitance is defined as the amount of energy can be store to raise the body's temperature one unit of temperature. Table 3 shows the comparisons between the electric and thermal systems. In this dissertation, we will introduce a thermal model that follows the pattern of circuit theory.

Table 3 Analogy between Electric and Thermal Systems

Quantities	Electric	Thermal
State Variable	Charge	Heat
Effort	Voltage	Temperature
Flow	Current	Heat flow
Dissipative Element	*Resistor*	Thermal resistance
Storage	Capacitor/Inductor	Thermal capacitor

2.2 The Concept of Patterns

A Pattern is an efficient concept that is based on physical laws that appear in different disciplines. It considers being one of the cross-cutting concepts. Patterns are important in science because they initiate questions. When we see a pattern, we want to explain why it occurs that way and why that pattern exists. These questions eventually can lead to better explanations, and they can potentially lead to scientific theories. In engineering, we test things over and over to see if there is a pattern of failure or we can use patterns to improve solutions to the human's problems. Patterns are everywhere; we find patterns in petals of the flowers or even we can find patterns in molecules, like the nucleotide sequence in DNA. As scientists, we need to recognize those patterns in order to think of new discoveries and develop better modeling.

The proposed theory is based on the concept of energy patterns. Energy flow has the same pattern in all domains, and therefore the same equations are applied. Energy equations are well-defined in some energy systems and are not defined properly in other energy systems. The missing equations will be defined in these systems based on the concept of energy patterns.

We will discuss various examples to show how a pattern can be common in different disciplines and things that appeared to be different are all the same at the pattern level.

2.2.1 A Generalized Mathematical Equations

Mathematical expressions and equations are abstract concepts; it has no physical meanings. For example, the number "1" is an abstract pattern. However, "1" apple, "1" orange, and "1" flower indicate something that everybody knows. Therefore, "1" is the pattern of one apple, one flower, etc.

The common thing between "1" flower, "1" apple, and "1" is oneness, and therefore, the pattern of oneness can be extracted.

2.2.2 A Generalized Behavior

We will discuss another example that shows how the same pattern could be applied to different systems. The pattern of energy oscillation can be observed when a system has two different types of reactive elements as shown in Fig. 3. In the absence of resistance, the energy in both systems remains constant and is changed between two reactive elements (between capacitance (C) and inductance (L) or between the stiffness of a spring (K) and mass (m). There is nothing common between electrical and mechanical systems (electricity and movements), and yet my brain tells us there is something similar, which is the oscillation of energy. The mathematical equations that describe the energy oscillation will be the same for electrical and mechanical energy systems.

$$i(t) = i_0 \cos(w_0 t)\,, w_0 = \frac{1}{\sqrt{LC}}, \tag{28}$$

$$u(t) = u_0 \cos(w_0 t)\,, w_0 = \frac{1}{\sqrt{M/_K}}, \tag{29}$$

where i is the electric current, u is the velocity, and w

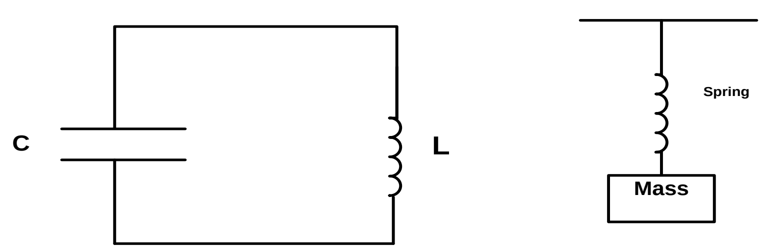

Fig. 3 Electrical and mechanical systems with two reactive elements

2.2.3 *A Generalized Geometric Form*

The following example shows a delta of Mississippi river and a human lung. Both have similar geometry because there is underlying their similar design. It is not a cosmic coincidence. Both of them have the same flow system. There is a flow from high concentration to diffuse. In other words, whenever a flow goes from high concentration to low, it always branches out. In fact, there are laws driving this pattern[47].

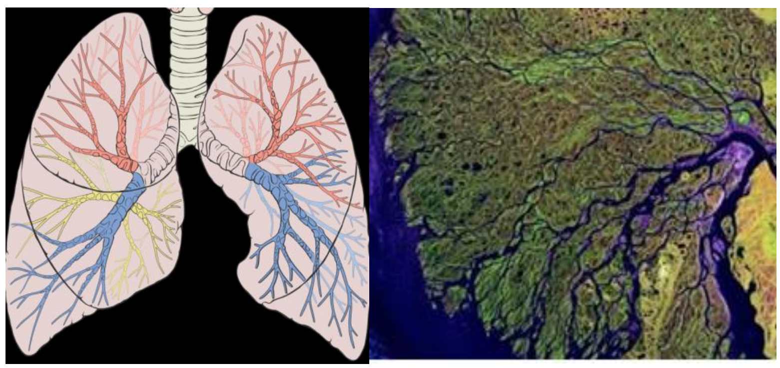

Fig. 4 Delta of Mississippi river and human lung[48, 49]

This research investigates the common energy patterns in various systems. An electromagnetic system is used as an archetype system for extracting the energy patterns since it is well-documented domain and its energy equations are established and complete. All energy equations in an electromagnetic domain will be visited in order to observe the energy patterns that are governed by certain laws. In other words, the energy equations of the electromagnetic domain will be investigated at the pattern level.

2.2.4 Periodic Table

The periodic table is "a tabular arrangement of the chemical elements, organized on the basis of their atomic numbers, electron configurations, and recurring chemical properties" [50]

The periodic table has a long and very interesting history. In this thesis, we will not go into history. We only need to show the concept of pattern was involved to develop the periodic table, in which its current form is attributed most often to Russian chemist Dmitry Mendeleev. Mendeleev arranged the elements in the periodic fashion because he found that certain elements behaved similarly to others. For example, the element sodium (Na) and the element potassium (K) behaved very similarly to one another, likewise the element bromine (Br) and iodine (I) behaved very similarly to one another. We know now that the reason for these periodic trends the periodic behavior is the number of valence electrons. For example, both the element sodium (Na) and the element potassium (K) have one valence electron and magnesium which behaves differently from sodium has two valence electrons and likewise calcium directly beneath it in the periodic table has two valance electrons. In other words, the number of valence electrons causes the elements to behave differently from one to another. But, if they are in the same column on the periodic table, like sodium with potassium and magnesium with calcium, they should have the same number of valance electrons and behave chemically similarly to one another. So, the periodic trends are a direct consequence of the number of valence electrons that each element possesses and that is all they are organized in the periodic tables, as shown in the figure below. From the concept of pattern, Mendeleev can predict undiscovered elements based on some pattern he observed in the Table [50].

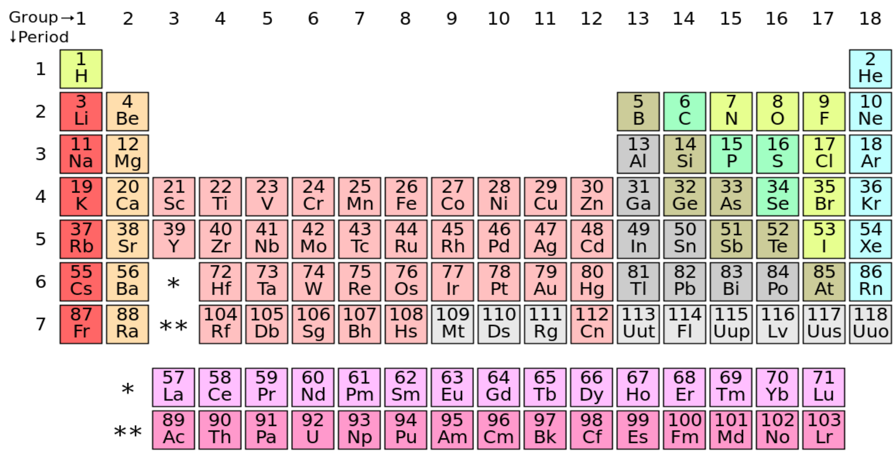

Fig. 5 Periodic table of elements[51]

2.3 Gyrator Theory

Energy can disappear from a domain (an electrical domain), and it appears in another domain (a magnetic domain). It travels in time and in space and holds the same dimensions. In an electric motor, energy travels between electromagnetic domains to the mechanical domain maintaining its integrity. In other words, energy is in one domain and it suddenly disappears and gyrates to something else. This phenomenon is called gyrator.

The gyrator is a power-invariant, multiport network that converts the voltage or a current quantity of one of the networks into its dual with respect to its gyration constant (g).

Gyrator theory was invented by Tellegen [52] and used in linear circuits. The gyrator is a power input and is equal to power output. It is based on a two-port network that converts the effort or flow quantity of one domain to its dual. Mathematically, it can be described as

$$\text{effort}_1 = -\text{g} \cdot \text{flow}_2, \tag{30}$$

$$\text{effort}_2 = \text{g} \cdot \text{flow}_1. \tag{31}$$

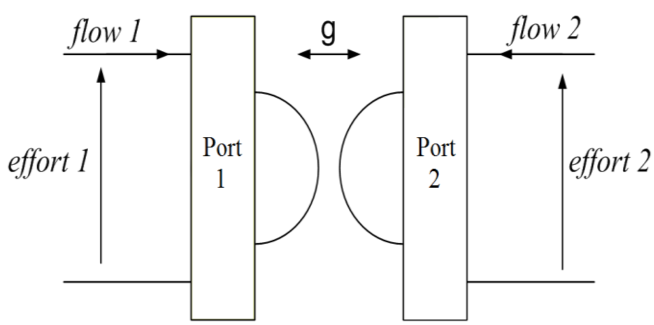

Fig. 6 Symbolic representation of a two-port gyrator

A symbolic representation of the conventional gyrator is presented in Fig. 6 Symbolic representation of a two-port gyrator If we assume an iron core coil to be a gyrator where the primary network is at the electric regime and the secondary network is at the magnetic regime and both networks are interconnected through the windings being its number of turns (*N*) the gyrator constant, as shown in Fig. 6 Symbolic representation of a two-port gyrator We can identify the effort and flow quantities of both regimes comparing the gyrator equations (30)and (31) with the system's defining equations, Faraday's and Ampere's laws, given by (32) and (33) respectively.

$$v_e = -N \cdot \frac{d\varphi}{dt}, \tag{32}$$
$$mmf = N \cdot i_e. \tag{33}$$

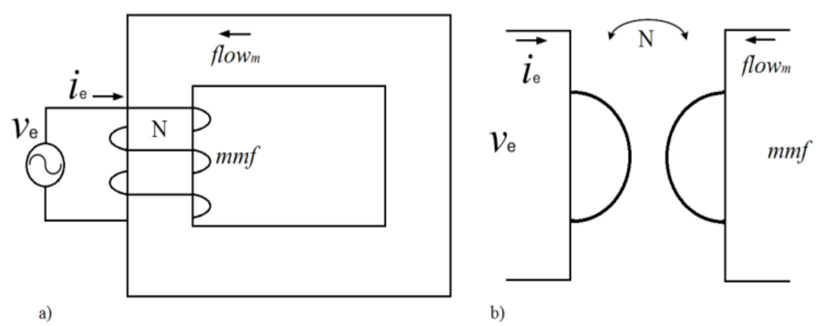

Fig. 7 Representation of an iron core coil as a) physical system, b) gyrator

It is evident that the set of equations are similar in form and functionality. Equations (30) and (31) suggest that the electric voltage (v_e) is the effort quantity of the electric network while the rate of flux ($d\varphi/dt$) is the flow quantity of the magnetic one. Similarly, (32) and (33) presents the magneto-motive force (*mmf*) and the electric current (i_e) as the effort and flow quantities of the magnetic and electric regime, respectively.

In order to verify that these quantities satisfy the power equation, we perform a dimensional analysis to (34) and (35) obtaining watt units.

$$p_e = v_e \cdot i_e, \tag{34}$$
$$p_m = mmf \cdot \frac{d\varphi}{dt}. \tag{35}$$

Using the rate of magnetic flux (*dφ/dt*) as flow is the fundamental modification of the reluctance model. It is the key to define the rest of the parameters (magnetic resistance, inductance and capacitance) needed to standardize the magnetic model. This will be discussed in the following section [42].

2.4 Power-Invariant Magnetic System

As mentioned earlier, in the conventional magnetic model the power equation is not satisfied. This means that either the effort or flow quantity is not properly defined. We will use gyrator theory in order to identify the ill-defined quantity and redefine it [42].

2.4.1 Magnetic Fundamental Quantities

In this model, six scalar quantities are defined in order to fully model the energy transfer process, specifically for the magnetic regime. An electric analogy is used as the basis to derive the magnetic model. This is because there is an intrinsic coupling between the two systems.

Fundamentally, the magnetic phenomenon is the result of the magnetization of the magnetic dipole moments, similar to the electric phenomenon being the result of the polarization of the electric-bound charges in dielectric materials. This analogy has been used to define the magnetic conserved quantity.

The scalar quantity that represents the magnetization (M) of the magnetic material due to a magnetic field (H) is the magnetic flux (φ) and it is expressed as,

$$\varphi = \int_S \mathrm{BdS} = \int_S \mu_0(\mathrm{M} + \mathrm{H})\mathrm{dS}. \quad (36)$$

Similar to the electric flux, the magnetic flux (φ) was used as the magnetic conserved quantity. In order to be consistent with the electric analogy, the magnetic conserved quantity is the flux (φ) or a magnetic- bound charge (q_m).

The flow can be defined as the movement of a conserved quantity through certain cross sectional area per unit of time. In the electric regime, the flow or currents are divided into two classes, conduction currents and displacement currents. Conduction currents result from the movement of free-charged particles in a conductive medium. The motion of these particles generates heat and therefore, it is usually associated with energy losses. Mathematically it is given by,

$$i_{e,cond} = \frac{dq_e}{dt} \quad [A] \quad (37)$$

Displacement currents were introduced by James Clerk Maxwell in 1861 in order to satisfy Ampère's circuital law which establishes that currents always flow in a closed path. It satisfies the current through capacitors as there are no free charges moving inside the dielectric medium. Mathematically it is given by

$$i_{e,disp} = \frac{d\psi}{dt}[A], \quad (38)$$

where ψ is used to denominate the electric flux [C].

Displacement currents play a little role in metallic conduction. In metals they are a dwarf into insignificance by the magnitude of the conductive current; but in insulators where conduction currents are weak, the displacement current may well play a role even at low frequencies and most certainly when the frequencies are elevated [53].

In magnetic systems, the magnetic current is defined as a displacement current similar to a dielectric material. This is based on the fact that both materials need to be polarized in order to react. Furthermore, the expression of flow obtained from the iron core coil as a gyrator suggests that

$$i_{m,disp} = \frac{d\varphi}{dt} \quad [Wb/s], \tag{39}$$

which is similar in form, functionality and origin to (38) as both are based on flux. In this case φ is used to specify the magnetic flux.

Similar to electric displacement currents, the magnetic displacement currents are not based on the movement of magnetic free-charged particles as the existence of such charges have not been discovered. Instead, they are based in the rate of change of magnetic fields. However, the displacement currents can be recognized as a moving-charge current related to the movement of the magnetic dipoles during the magnetization of the magnetic material. It is given by (39) or in terms of its current density as,

$$J_{m,disp} = \frac{dB}{dt} \, [T/s], \tag{40}$$

Since $B = \mu_0(M + H)$, the magnetic displacement current can also be expressed in terms of the magnetization as,

$$J_{m,disp} = \mu_0 \frac{d(M+H)}{dt} \quad [T/s] \tag{41}$$

In general terms, the effort can be defined as the force needed to generate a flow or as the force needed to produce work. In electrical systems, the effort quantity is most commonly known as voltage (V), electric potential (Ue) or electromotive force (emf). It is the force needed to move a charged particle from one point to another in the presence of an electric field. Mathematically it can be expressed as,

$$\mathrm{emf} = \mathrm{v_e} = \int \mathrm{Edl}\,[\mathrm{V}], \tag{42}$$

where E is the electric field and dl is a differential element of a path.

In magnetic systems, the effort quantity has been specified as the magnetic potential (Um) or magnetomotive force (mmf), analogous to the electromotive force. In [42], the magnetic voltage is analogous to electric voltage. Mathematically it can be expressed as,

$$\mathrm{mmf} = \mathrm{v_m} = \oint \mathrm{Hdl} \quad [\mathrm{t{\cdot}A}] \tag{43}$$

where H is the magnetic field and dl is a differential element of a closed path.

In order to satisfy the analogy, the mmf must also be defined as the force needed to generate a magnetic current. This statement contradicts the popular notion that there is no flow of anything in a magnetic circuit corresponding to the flow of charge in an electric circuit. However, it has been established in this model that the magnetic current is a displacement current and can be considered as the result of magnetization of the magnetic dipoles in magnetic materials, similar to the displacement current related to the bound or polarized charge of an electric insulator. In both cases, an effort is needed to create the polarization of the bound charges.

As a standard model element, resistance can be generalized as the parameter that causes energy to be released as heat due to the flow of current in a material. Its generalized definition is,

$$\mathrm{R} = \frac{\mathrm{effort}}{\mathrm{flow}}. \tag{44}$$

In electric circuits, the resistance relates the electric voltage (ve) and current (ie) flowing through a conductive material,

$$R_e = \frac{v_{Re}}{i_{Re}} \quad [\Omega]. \tag{45}$$

Also, its value can be expressed in terms of the intrinsic property of the material (resistivity, ρ_e [Ω·m] or conductivity, σ_e [Ω-1/m]) and geometry (length [L] and area, S [L^2]) of the specimen. This is given as

$$R_e = \frac{\int Edl}{\int J_e dS} = \frac{\int Edl}{\int \sigma_e EdS} = \rho_e \frac{l}{S}[\Omega]. \tag{46}$$

Similarly, in magnetic circuits was defined as a magnetic equivalent resistance based on the general definition. It is the quantity that measures the amount of magnetic current the material allows to flow when certain voltage is applied. It also causes energy to be lost as heat.

The magnetic current (i_m) can be related to the magnetic voltage (v_m) through the following equation:

$$R_m = \frac{v_{Rm}}{i_{Rm}} \ [\Omega^{-1}], \tag{47}$$

or in terms of the intrinsic property of the magnetic material (magnetic resistivity, ρ_m [Ω^{-1}·m] or magnetic conductivity, σ_m [Ω/m]) and geometry (length [L] and area, S [L^2]) of the specimen as,

$$R_m = \frac{\oint Hdl}{\oint J_m dS} = \frac{\oint Hdl}{\oint \sigma_m HdS} = \rho_m \frac{l}{S}[\Omega\text{-}1]. \tag{48}$$

It is important to point out that there is a fundamental difference between the electric and magnetic resistance and this has its origins in the mechanism that produces the flow of currents. The electric resistance describes the opposition that the conductive media presents to the flow of free charges. Therefore, it reflects the heat losses due to the kinetic energy released by the movement of these free charges. However, as previously mentioned, magnetic currents result from the polarization or magnetization of the magnetic dipoles in the magnetic material, similar to the displacement electric currents. The power dissipated as heat is the result of the resistance of the magnetic material to being magnetized.

The power dissipated by the magnetic resistance can also be expressed in terms of an analogy to the Joule's law when the resistance is a constant value. That is,

$$P_{Rm} = V_{m,rms} \cdot I_{m,rms} = R_m \cdot I_{m,rms}{}^2 = \frac{1}{R_m} \cdot V_{m,rms}{}^2, \quad (49)$$

which is the average of the instantaneous power [W].

The capacitance can be generalized as the parameter that determines the amount of energy stored in the medium due to an applied effort in that medium. Mathematically it is expressed as,

$$C = \frac{q_{rw}}{\text{effort}} \quad (50)$$

where q_{rw} stands for the conserved quantity in the medium.

In the electrical regime, the capacitance measures the ability of the medium to hold a charge (q_e) due to a given potential (v_e). For example, in an air capacitor it describes the amount of energy stored in the electric field. Electrical capacitance is expressed as,

$$C_e = \frac{q_{Ce}}{v_{Ce}} \quad [\text{F}]. \quad (51)$$

For a dielectric capacitor with its intrinsic dielectric property and geometry, capacitance can be expressed as,

$$C_e = \frac{\oint DdS}{\oint Edl} = \frac{\oint \varepsilon EdS}{\oint Edl} = \varepsilon \frac{S}{l} \ [\text{F}]. \quad (52)$$

where l [L] and S [L^2] represent the depth and area of the dielectric, respectively and ε [F/m] represents permittivity of the dielectric material, which determines the ability of a material to polarize in response to an electric field.

In magnetic media, the capacitance determines the ability of the media to store energy due to a given magnetic potential or effort (v_{Cm}) and can be expressed as,

$$C_m = \frac{q_{Cm}}{v_{Cm}} \text{ [H]}. \tag{53}$$

Similar to the resistance, the capacitance depends on a property of the material medium. Its numerical value depends on the intrinsic property of the magnetic material (permeability, μ [H/m]) and the geometry of the material (length, l [L] and area, S [L2]). This is expressed as,

$$C_m = \frac{\oint BdS}{\oint Hdl} = \frac{\oint \mu HdS}{\oint Hdl} = \mu \frac{S}{l} \quad \text{[H]}. \tag{54}$$

At this point, it is evident that our magnetic capacitance plays the same role as the permeance in the conventional reluctance model. Therefore, we have verified that the permeance and its inverse, the reluctance, are in fact energy storage elements and not the perceived dissipative elements.

Energy stored by a capacitance can be generally expressed as

$$W_{Cm} = \int v_{Cm} dq_{Cm} \text{[J]}. \tag{55}$$

If the capacitance is a constant value, then the energy stored can be expressed using a more familiar expression,

$$W_{Cm} = \frac{1}{2} C_m V_{Cm}^2 \text{[J]}. \tag{56}$$

In order to explain the inductance as a generalized element we need to remember the first law of thermodynamics, energy is neither created nor destroyed only transformed. This is important because energy can either be kept in the same medium of work or transformed into another medium in order to be stored.

The most common example of this process occurs in the electric regime when energy is stored in magnetic medium due to the flow of electric current. The element that describes this process is known as electric inductance and is expressed as,

$$L_e = \frac{N\varphi}{i_{Le}}, \tag{57}$$

where φ is the magnetic flux and i_{Le} is the electric current. The number of turns (N) appears in (57) because a gyration from the magnetic to the electric regime is taking place.

Equation (57) can also be expressed in terms of the intrinsic property of the magnetic material (permeability, μ [H/m]) and the geometry of the material (length, l [L] and area, S [L^2]) as,

$$L_e = N^2 \frac{\oint BdS}{\oint Hdl} = N^2 \frac{\oint \mu HdS}{\oint Hdl} = N^2 \left(\mu \frac{S}{l}\right)[H]. \tag{58}$$

Similarly, in magnetic systems the inductance determines the amount of energy stored in a dual medium due to the flow of magnetic current (i_m). As the electric and magnetic regimes are coupled, we consider the electric medium as the dual of the magnetic regime; therefore, the magnetic inductance can be expressed as,

$$L_m = \frac{Nq_e}{i_{Lm}}. \tag{59}$$

The magnetic inductance can also be expressed in terms of the geometry of a material, length (l) and area (S), and its permittivity (ε) as,

$$L_m = N^2 \frac{\oint DdS}{\oint Edl} = N^2 \frac{\oint \varepsilon EdS}{\oint Edl} = N^2 \left(\varepsilon \frac{S}{l}\right)[F] \tag{60}$$

The energy stored by a magnetic inductance can be expressed either by,

$$W_{Lm} = \frac{1}{2} L_m I_{Lm}^2 [J]. \tag{61}$$

Finally, the inductance can be generalized as the element that stores energy in a dual regime or medium due to a flow and it can be expressed as,

$$L = \frac{q_{drw}}{flow}, \tag{62}$$

where q_{rw} stands for conserved quantity in the dual medium.

Table 4 presents the comparison between the invariant magnetic model and the reluctance model. The power-invariant magnetic model is helpful in more accurately modeling the magnetic phenomena. However, in this dissertation, we will show that the magnetic inductance as defined in [42] represents the electrical capacitor in the magnetic side, and therefore, it will not be considered as a magnetic element.

Table 4 Comparison between Power-Invariant and Reluctance Models[42]

Quantities	Power-Invariant	Reluctance
Conserved Quantity	Magnetic Flux [Wb]	**?**
Flow	Magnetic Current [Wb/s]	Flux [Wb]
Effort	Magnetic Voltage [t·A]	MMF [t·A]
Dissipative Element	Magnetic Resistance [Ω^{-1}]	Reluctance [H^{-1}]
Energy Storage Element	Magnetic Capacitance [H]	**?**
Energy Storage Element	Magnetic Inductance [F]	**?**

3 ENERGY DYNAMIC THEORY

3.1 Research Objectives

The state of understanding of energy has remained unchanged for nearly150 years. The only new contribution has been Einstein's discovery of the equivalence of mass and energy.

The theories and mathematical and engineering models based on the above understandings have not been able to explain many theoretical and empirical questions and discrepancies that arise in the practical study and applications of energy [54, 55]. Some of these questions are listed below.

a. Why is the second law of thermodynamics true?
b. Why is the Carnot efficiency principle true?
c. Why is there an asymmetry between the electrical and magnetic equivalent circuit models? For example electrical resistance not only impedes electrical current but also dissipates electrical energy from the circuit. However, the magnetic circuit model (reluctance and flux) does not follow the same pattern.
d. Why is the dimension of mass present in energy stored electrically, for example in the electrical field of a capacitor, or the magnetic field of an inductor? There is mass needed in the electrical charge and in the electrical models.

e. Why do the dielectric constant of free space and the magnetic permeability of free space have dimension of mass in them? The dielectric constant of free space defines the forces between two charges, without the presence of mass.

f. If you are accelerating a charge or a mass blindfolded, can you tell which one you are accelerating? Why or why not?

g. How do you quantitatively calculate the change of entropy in an electrical circuit, or when energy is dissipated from the electrical circuit? In other words, how do you make practical use of the definition of entropy to solve engineering and physics problems?

h. Einstein showed that mass can be destroyed by turning into energy. Can charge be destroyed? Why is there no theory addressing this question?

i. Why is there a discrepancy between the observed and calculated energy content of a proton, based on the conventional theory of energy?

j. Why do electrons (charges) of complimentary spins pair up?

k. Can masses with spins pair up as well?

The above are but a sample of questions and limitations of the theory of energy dynamics and models based on them. These limitations not only have handicapped our understanding of the universe around us, but also the engineering tools and machines that are possible to conceive, design, simulate, and build [56-58].

3.2 Our Proposition and Motivations

We have proposed a unified pattern of energy dynamics in all of its forms. This proposition is based on the principle that energy must behave the same in all its forms and in every domain that it may reside. This simple proposition results in many new discoveries about the behavior of energy in its static form (energy stored in a stationary point in space and time), as well as its dynamic form (energy traveling in space-time in one form, one domain, or being converted, transmutated, to another form, or domain).

Simply put, we will use the well-known mathematical patterns of energy in every domain and ask: do these patterns apply in other domains. Since the electromagnetic domain has the most developed mathematical patterns we will use this as the archetype domain. And use Maxwell's equations and circuit theory as the foundation of energy dynamics in other domains, such as thermal and mechanical, etc.

However, before we did this, we have corrected some of the discrepancies of magnetic circuit theory that have survived for more than 100 years. The result is better modeling tools for designing inductors, transformers, electric machines, and electromechanical engineering systems. Some of these models have already been developed and are delivering results that were not obtainable from the conventional models.

The proposed theory of energy dynamics has been developed for the first time. The application of this theory to specific engineering systems such as thermal, mechanical, and mixed modes is underway. However, several discrepancies in modern physics, engineering, and cosmology are already easily explainable based on this theory.

For example, we can show the following:

1. Energy changes dimensions as it goes from one domain to another: it transmutes as it is transmitted through space-time and across domain boundaries.
2. There is no dimension of mass in electrical constants of physics. Electrical and "mechanical" domains are completely independent.
3. There is no mechanical mass in the dimensions of electrical and magnetic energies.
4. There is another form of momentum in the electrical domain, described for the first time.
5. There is another form of gravitational force (co-gravity) that is responsible for the inertia of mass. This co-gravity is described for the first time. It explains many of the observed behavior in physics and in cosmology, such as the paring of electrons, alignment of the axis of rotation of the planets and the sun, the acceleration of the observable universe, etc.
6. There are two more undiscovered constants of free space: the gravitational constant and the co-gravitational constant of free space. These two constants are responsible for the propagation of gravitational waves at the speed of light in free space. Further, the speed of gravitational waves is slower in dense media, such as gases, liquids, and solids. This is

responsible for errors in the microgravity measurements of the topography of the earth and other planets from the orbit.

7. There may be a new source of nuclear energy yet to be discovered, based on the inhalation of charge, as predicted by our theory:

$$E = qc^2 \tag{63}$$

8. It may be possible to design, model, and build new energy conversion machines, such as thermo-electric oscillators, thermal lasers, thermo-acoustic-electrical generators, etc.
9. Physical domains cause an inversion of variables and parameters (gyration) at their boundaries to transmute (change of dimensions) and transmit (change of space-time) energy.
10. The discrepancy between the measured and calculated energy content of the proton may be explainable by the independent energy contents of its charge and mass.
11. Mass and charge warp space-time in the same way but to different extents, having to do with the electric, magnetic, gravitational, and co-gravitational constants of space.
12. Magneto-mechanical energy conversions (transmutation) can be explained without the use of “co-energy” fudge factor.

The above are but samples of the new results from the proposed theory of energy dynamics.

This research describes how energy can be stored and how it is converted. When energy is stored, it is stored in space and in time within one medium. When it is converted, it travels to another medium, such as a mechanical medium.

Based on the work that has been done so far, many inconsistencies and gaps in the existing theory have been discovered. Modeling, simulations, calculations, and designs cannot be performed because parameters and definitions in the existing theory are missing. Our theory is based on the fact that energy pattern is the same in all domains. It is a guideline that is used to establish a very consistent and elegant theory that applies in all domains. This theory can be used to enhance the modeling in [59-64]

The starting point is to investigate the pattern of an electromagnetic domain, which will be used as our archetype since it is fully established and well documented domain. The proposed theory started from a simple concept that is called an energy source. An energy source is a box where energy resides. It is an abstract concept and is completely stationary, has a finite amount of energy, does not move in space, and does not change in time. The origin of energy and yet how it is trapped are not of interest; it is cosmology. Something has changed in the box to indicate that energy is there, so there is a change of a state in that box. Those changes could be a charge in a capacitor, compression in spring, or compression of gas as shown Fig. 8.

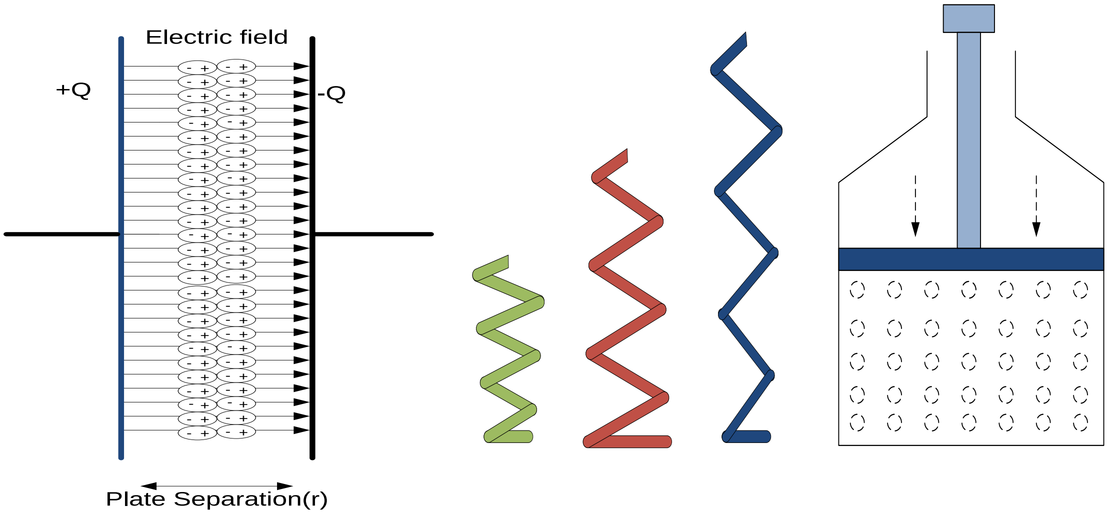

Fig. 8 Examples of change of states in three different systems

We call this an energy source, and it does have some characteristics. Another important concept in our energy dynamics theory is an energy domain, which is defined as the type of a box that energy is in. A domain is singularly defined by a conserved quantity that represents the material or the mass of that box. For example, charge is the mass of the electrical domain and is conserved quantity.

3.3 Electrostatic

Charge is similar to mass in the gravitational domain; it represents the intrinsic property of the domain and produces an electric field (effort) that affects other charges as shown in Fig. 9. The electrical and gravitational fields are defined as

$$\vec{E} = \frac{q}{4\pi\varepsilon r^2}\vec{r}, \tag{64}$$

$$\vec{G} = \frac{Gm}{r^2}\vec{r}, \tag{65}$$

where $\vec{E}$ is the electric field, $\vec{G}$ is the gravitational field, q is the electric charge, ε electric permittivity, and G is a gravitational constant.

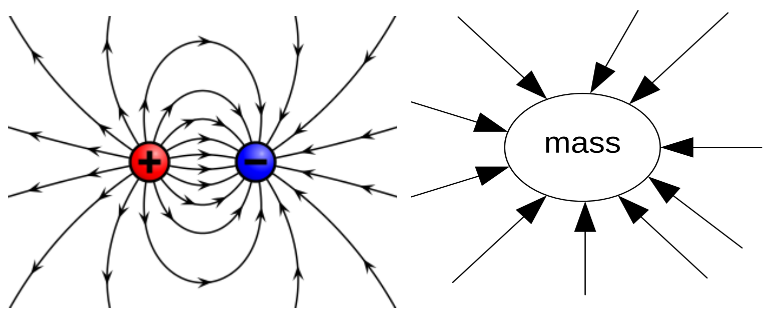

Fig. 9 The strength of an electric field [65] and a gravitational field

To indicate the presence of an electric field, a test charge (q_{test}) is placed inside the field. The test charge will experience an electrical force, which is defined as

$$\vec{F} = q_{test}\vec{E}. \tag{66}$$

The gravitational force is also defined as

$$\vec{F} = m_{test}\vec{G}\ [MLT^{-2}]. \tag{67}$$

The force dimension of (67) is MLT^{-2}, and therefore the dimension of the gravitational field $\vec{G}$ is LT^{-2}. The gravitational field represents the acceleration of the force, which is independent of mass. If the pattern of the gravitational field is applied to the electric field, the dimension of the electric field will be time-space dependent, as shown below.

$$\vec{G} = \frac{Gm}{r^2}\vec{r}[\ LT^{-2}], \tag{68}$$

$$\vec{E}_e = \frac{\mathrm{q}}{4\pi\varepsilon_e \mathrm{r}^2}\vec{\mathrm{r}}[\,\mathrm{LT}^{-2}]. \tag{69}$$

Moreover, if the pattern of electrical field is applied to the gravitational field, a new concept, which is ε_g will be defied as in (70).

$$\vec{G} = \frac{\mathrm{m}}{4\pi\varepsilon_g \mathrm{r}^2}\vec{\mathrm{r}}[\,\mathrm{LT}^{-2}]. \tag{70}$$

It can be concluded that the force, space, and time are universal concepts, and therefore an epsilon will be redefined in such a way that disturbs the space-time.

When the charges or masses are separated, an energy source is created as shown in Fig. 11, and therefore, the energy source in the electrical and gravitational domains are defined as

$$W_e = \int \vec{F}_e \,.\, d\vec{r}[QL^2T^{-2}], \tag{71}$$

$$W_g = \int \vec{F}_g \,.\, d\vec{r}[ML^2T^{-2}], \tag{72}$$

where $\mathrm{W_e}$ is the electrical energy, $\mathrm{W_g}$ is the gravitational energy, $\vec{\mathrm{F}}_\mathrm{e}$ is the electrical force, and $\vec{\mathrm{F}}_\mathrm{g}$ is the gravitational force. As seen in (71) and (72), the dimension of energy is a domain dependent; it depends on the mass of the domain. This shows that when energy travels from an electrical domain to a gravitation domain, it mutes (it changes its dimension), as shown in Fig. 10.

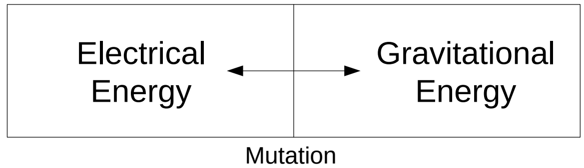

Fig. 10 Energy mutation between two domains

This can be represented in (73)

$$W_e = M_{mut} W_g, \tag{73}$$

where M_{mut} is the mutation factor, and is defined as

$$M_{mut} = \frac{q}{m}. \tag{74}$$

To sum up, charge (q) in the electrical domain is the mass of the electrical domain. When the charge is in space, it produces a vector field around itself as shown in Fig. 11.

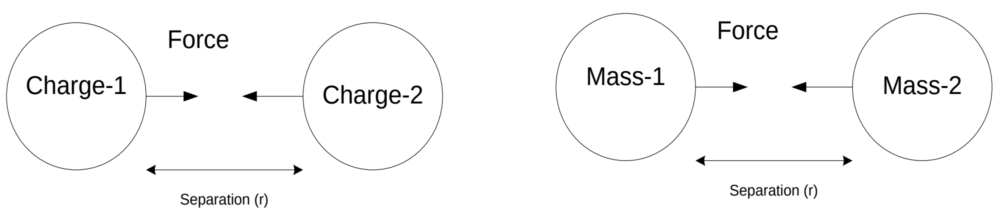

Fig. 11 Separation of electric charges and mechanical masses

A vector field (an electric field [66]) is the characteristic of the space that disturbs space-time and is defined by

$$\vec{E} = \frac{q}{4\pi\epsilon r^2}\vec{r}[LT^{-2}]. \tag{75}$$

To indicate the presence of an electric field, a test charge (q_{test}) is placed inside the field. The test charge will experience an electrical force, which is defined as

$$\vec{F} = q_{test}\vec{E}[QLT^{-2}]. \tag{76}$$

The gravitation and electric force are defined as

$$\vec{F_g} = \frac{m_1 m_2}{4\pi\, \varepsilon_g r^2}\vec{r} = M\overrightarrow{\boldsymbol{G}}[MLT^{-2}], \tag{77}$$

$$\vec{F_e} = \frac{q_1 q_2}{4\pi\, \varepsilon_e r^2}\vec{r} = Q\overrightarrow{\boldsymbol{E}}[QLT^{-2}], \tag{78}$$

where $\vec{F_g}$ is the gravitational force, $\vec{F_e}$ is the electrical force, q is electric charge, M is mass, ε_g is the gravitational epsilon, and ε_e is the electrical epsilon.

This pattern suggests two different forces (electrical and gravitational forces) that are independent; each one is in a different universe and they only share space and time. For example, if mass and electric charge are in space, and there is an object that has both mass and charge (charge and mass are in the same object), as shown in

Fig. 12, the object will experience two different forces ($\vec{F_e}$ and $\vec{F_g}$). The resultant force in this case is $\vec{F}_R$.

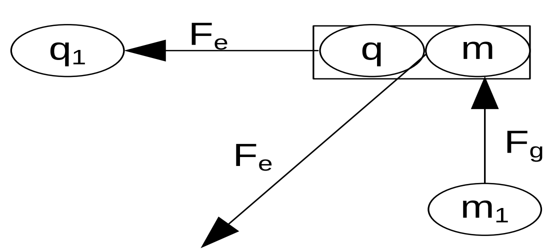

Fig. 12 The resultant force from charge and mass

Also, the pattern of the electric force suggests that there is the gravitational epsilon ($\varepsilon_g = \varepsilon_0 . \epsilon_r$) (epsilon of gravity). This implies that the force between two objects in a vacuum is different from that in the atmosphere, water, or even in solid. In other words, the object will interact differently, since the medium introduces its own gravitational properties and epsilons. For example, if the force between two objects in free space is defined in (79), the force between two objects in water is then defined as in

$$\vec{F_g} = \frac{m_1 m_2}{4\pi\ \varepsilon_{g0} r^2}\vec{\mathrm{r}}, \tag{79}$$

$$\vec{F_g} = \frac{m_1 m_2}{4\pi\ (\varepsilon_{g0} . \varepsilon_1) r^2}\vec{\mathrm{r}}. \tag{80}$$

where ε_{g0} is permittivity in free space, and ε_1 is permittivity in water.

After we defined the effort in the electrical domain, flow can be defined when a single charge is moving with a velocity [67], as follows

$$\vec{j} = q\vec{v}, \tag{81}$$

where v is the average speed of the moving charges.

In order to determine the magnitude of the force field at any point in space at each instant of time, a scalar field should be defined as effort. The effort is the force needed to move a charged particle from one point to another while in the presence of an electric field. Mathematically,

$$V = -\int \vec{E}.d\vec{l} \tag{82}$$

where $\boldsymbol{E}$ is the electric field and $\boldsymbol{dl}$ is an element of the path from point from two points.

An realization of an energy source happens when the charges are enclosed between two points. The electric field in this case is a uniform electric field. A charge does not have to be a point charge; it could be a cloud of charges. For a given distance(r), one can enclose a certain amount of charges. The best way to represent this is by defining the charge surface (charge density). A surface charge is of importance because at the surface of the sphere, one is unable to decipher where charges are. Under the influence of an electric field, the realization of the container is defined as

$$\mathrm{C} = \frac{\vec{D}}{\vec{E}}[QL^{-2}T^{2}]. \tag{83}$$

The current density j is parallel to the electric field. The relationship between the electric field and the current density defines the resistivity of the material, which is donated by ρ or the inverse of the conductivity σ.

$$\rho = \frac{\vec{E}}{\vec{J}} \tag{84}$$

An electromagnetic domain the coupling between the electrical and magnetic domains [68-70]) are defined through Maxwell equations

$$\nabla \times E = -\mu \frac{\partial H}{\partial t}, \tag{85}$$

$$\nabla \times H = J + \varepsilon \frac{\partial E}{\partial t}, \tag{86}$$

where $\vec{H}[QL^{-1}T^{-1}]$ is the magnetic field intensity, and $\mu[LQ^{-1}]$ is the permeability of the medium.

Equations of electromagnetic wave equations can be derived from (85) and (86, as follows

$$\nabla^2 \times \vec{E} = -\mu\varepsilon \frac{\partial^2 \vec{H}}{\partial t^2}, \quad (87)$$

$$\nabla^2 \times \vec{H} = -\mu\varepsilon \frac{\partial^2 \vec{E}}{\partial t^2}. \quad (88)$$

Poynting vector describes the power that leaves a region is equal to the energy that is stored and dissipated as a heat. In other words, it represents the direction of energy flux, which represents the rate of energy transform power unit area.

$$\nabla.\left(\vec{\mathrm{E}} \times \overline{\mathrm{H}}\right) = \vec{H}.\nabla \times \vec{E} - \vec{E}.\nabla \times \overline{H}, \quad (89)$$

$$\nabla.\left(\vec{\mathrm{E}} \times \vec{\mathrm{H}}\right) = -\mu\vec{H}\frac{\partial \vec{H}}{\partial t} - \epsilon\vec{E}\frac{\partial \vec{E}}{\partial t} - \vec{E}\vec{J}, \quad (90)$$

$$\nabla.\left(\vec{\mathrm{E}} \times \overline{\mathrm{H}}\right) = \vec{H}.\nabla \times \vec{E} - \vec{E}.\nabla \times \overline{H}, \quad (91)$$

$$\left(\vec{\mathrm{E}} \times \vec{\mathrm{H}}\right) = \frac{1}{2}\mu\vec{H}^2 - \frac{1}{2}\epsilon\vec{E}^2 - \sigma\vec{E}^2. \quad (92)$$

If an electron is traveling with a velocity u, it has two kinds of momentums, electrical and mechanical momentum.

$$p_{electron} = \mathrm{M_{mut}}(mu) + qu. \quad (93)$$

where $p_{electron}$ is the total momentum of electron.

3.4 Gravitational Field

Mass (m) is the mass of the gravitational domain. When mass is in space, it produces a vector field around itself. A vector field (a gravitational field [71]) is the characteristic of the space that disturbs space-time and is defined by

$$\vec{G} = \frac{\mathrm{m}}{4\pi\epsilon_g \mathrm{r}^2}\vec{\mathrm{r}}[\mathrm{L}T^{-2}]. \quad (94)$$

The way to indicate the presence of an electric field is when a test charge ($\mathrm{m_{test}}$) is placed inside the gravitational field. The test mass will experience a gravitational force, which is defined as

$$\vec{F} = \mathrm{m}_{test}\vec{\mathrm{G}}[QLT^{-2}]. \tag{95}$$

As mentioned before, electric charge is like mass in the gravitational domain. It represents the intrinsic property of the domain and it produces a gravitational field that affects other masses, just like mass produces a gravitational filed that affects other masses.

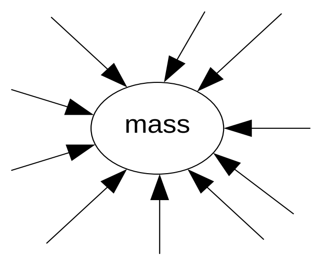

Fig. 13 The strength of a gravitational field for mass

When a single mass is moving with a constant velocity, flow happens. Flow can be defined as

$$\vec{J} = m\vec{v}, \tag{96}$$

where v is the average speed of the moving masses. When the flow is related to identical masses that cross a small cylinder that has a cross section area of A and length vt, current density (flux of current) is defined as

$$\vec{J} = nm\vec{v}[QTL^2]. \tag{97}$$

The flux of $\vec{J}$ through a particular surface gives the rate of flow charge through that surface, which is defined as

$$I_{gravity} = \int \vec{J}\,.\,d\vec{A}. \tag{98}$$

In order to determine the magnitude of the force field at any point in space at each instant of time, a scalar field should be defined as effort. Effort is the force needed to move a charged particle from one point to another while in the presence of a gravitational field. Mathematically,

$$V_{mec} = -\int \vec{G}.d\vec{l}, \tag{99}$$

where ***G*** is the gravitational field and ***dl*** is an element of the path from point from two points.

A realization of an energy source happens when the masses are enclosed between two points. The gravitational field in this case is a uniform field. Mass does not have to be a point mass; it could be a cloud of masses. For a given distance(r), one can enclose a certain two sheets of masses. The best way to represent this is by defining the mass surface (mass density). A surface charge is of importance because at the surface of the sphere, one is unable to decipher where charges are. Under the influence of a gravitational field the realization of the container is defined as

$$\mathrm{C} = \frac{m}{V_{mec}}[ML^{-2}T^{2}]. \tag{100}$$

Gravitational domain (coupling between the gravity and co-gravity domains)

$$\nabla \times \vec{G} = -\mu_{mec}\frac{\partial \vec{H}_{mec}}{\partial t}, \tag{101}$$

$$\nabla \times \vec{H}_{mec} = \vec{J} + \varepsilon_{mec}\frac{\partial \vec{G}}{\partial t}, \tag{102}$$

where $\vec{H}_{mec}[ML^{-1}T^{-1}]$ is the co-gravity field intensity, and $\mu_{mec}[LM^{-1}]$ is the permeability of the medium.

Poynting vector describes the power that leaves a region is equal to the energy that is stored and dissipated as a heat. In other words, it represents the direction of energy flux, which represents the rate of energy transform power unit area.

$$\nabla.\left(\vec{G}\times \vec{H}_{mec}\right) = \vec{H}_{mec}.\nabla\times\vec{G} - \vec{G}.\nabla\times\vec{H}_{mec}, \tag{103}$$

$$\nabla.\left(\vec{G}\times\vec{H}_{mec}\right) = -\mu_{mec}\vec{H}_{mec}\frac{\partial\vec{H}_{mec}}{\partial t} - \varepsilon_{mec}\vec{G}\frac{\partial\vec{G}}{\partial t} - \overrightarrow{GJ}, \tag{104}$$

$$\left(\vec{G}\times\vec{H}_{mec}\right) = \frac{1}{2}\mu_{mec}\,\vec{H}^2{}_{mec} - \frac{1}{2}\,\varepsilon_{mec}\vec{G}^2 - \sigma_{mec}\vec{G}^2, \tag{105}$$

Equations of electromagnetic wave equations can be derived from (85) and (86, as follows

$$\nabla^2\times\vec{G} = -\mu\varepsilon\frac{\partial^2\overrightarrow{H_g}}{\partial t^2}, \tag{106}$$

$$\nabla^2\times\overrightarrow{H_g} = -\mu\varepsilon\frac{\partial^2\vec{G}}{\partial t^2}. \tag{107}$$

Table 5 Analogy between Gravitational and Electrical Domains

Gravitational domain	**Electrical domain**
$\vec{\mathbf{G}} = \frac{\boldsymbol{m}}{\boldsymbol{4\pi\varepsilon_{mec}r^2}}\vec{\mathbf{r}}[\boldsymbol{LT^{-2}}]$	$\vec{E} = \frac{q}{4\pi\epsilon r^2}\vec{r}[LT^{-2}]$
$\vec{\boldsymbol{F}} = \boldsymbol{m}\vec{\mathbf{G}}[\mathbf{MLT^{-2}}]$	$\vec{F} = q\vec{E}[QLT^{-2}]$
$\mathbf{W} = \vec{\mathbf{F}}.\vec{\boldsymbol{l}} = \mathbf{m}\overrightarrow{\mathbf{Gl}}[\mathbf{M}\,\boldsymbol{L^2T^{-3}}]$	$W = \vec{F}.\vec{l} = q\overrightarrow{El}[Q\,L^2T^{-3}]$
$\boldsymbol{V_{mec}} = \vec{\boldsymbol{G}}.\vec{\boldsymbol{l}}[\boldsymbol{L^2T^{-2}}]$	$V_{ele} = \vec{E}.\vec{l}[L^2T^{-2}]$
$\boldsymbol{\varepsilon_{mec}}[\boldsymbol{ML^{-3}T^2}]$	$\varepsilon_{ele}[QL^{-3}T^2]$
$\boldsymbol{C_{mec}}[\boldsymbol{ML^{-2}T^2}]$	$C_{ele}[QL^{-2}T^2]$

From the above, it can be noted that as an electrical mass moves with a variable velocity in space produces a magnetic field (co electric field). A co domain of gravitational field is produced when the mass is in motions. In other words, if the mass is in motions it produces a new field (a co gravity field).

In short, in this section we propose a gravitational wave from the pattern of the electromagnetic wave. We also show how the energy and force dimensions are domain dependent; they depend on the mass of that domain. Also, we describe the gravitational wave through two fields, namely gravity and a co-gravity field. As of now, the existence of gravity wave has not been proved[72, 73]. However, the proposed theory suggests its existence.

4 USE OF GENERAL PATTERNS IN ENGINEERING DOMAINS

4.1 Electrical Domain

Charge (q) is the mass of an electrical domain in free space. When the charge is in space, it produces a vector field around itself. A vector field (an electric field) is the characteristic of the space that disturbs space-time and is defined as

$$\vec{E} = \frac{\mathrm{q}}{4\pi\epsilon \mathrm{r}^2}\vec{\mathrm{r}}[\mathrm{L}T^{-2}]. \quad (108)$$

To indicate the presence of an electric field, a test charge ($\mathrm{q}_{\mathrm{test}}$) is placed inside the field. The test charge will experience an electrical force, which is defined as

$$\vec{F} = \mathrm{q}_{test}\vec{\mathrm{E}}[QLT^{-2}]. \quad (109)$$

In order to determine the magnitude of the force field at any point in space at each instant of time, a scalar field should be defined as effort. Effort is the force needed to move a charged particle from one point to another while in the presence of an electric field, as defined in

$$V = -\int \vec{E}.d\vec{l}, \quad (110)$$

where ***E*** is the electric field and ***dl*** is an element of the path from two points.

A transition from a simple domain (electrical domain in free space) into an engineering domain (a constrain domain) requires some assumptions. For example, suppose a charge is in three dimensional spaces (sphere charge). If we constrain the space to a certain area, the electric field will be uniform. The charges (qd) are being displaced between two points, and therefore the electrical energy can be defined as

$$V = -\int \vec{E}.d\vec{l}, \quad (111)$$

$$W = \vec{E}q\overrightarrow{d}. \tag{112}$$

Electric field (E) is a uniform electric field, so the electric circuit voltage is defined as

$$V_e = \vec{E}\vec{d}[LT^{-2}] \tag{113}$$

We define V_e as the effort in the electrical engineering domain, and therefore q is the electric charge. As seen, this is highly conforming geometry and fixed d.

When exerting an electric field, the charges migrate from one place to another. If we want to structure a channel where the current goes through a surface, a current density should be defined as

$$\vec{J} = nq\vec{v}, \tag{114}$$

where n is the number of charges per unit volume, and n.q represents the charge density that indicates the conductivity of the material.

The incremental charge is defined as the incremental in charge density multiplied by the incremental volume.

$$Q = nq(\Delta t \times \vec{v}) \times A.\vec{n}, \tag{115}$$

The limit of the left side as the time goes to zero can be defined as

$$\frac{dQ}{dt} = nq(\vec{v}).A = I = nq\vec{v}A; \vec{J} = nq\vec{v} \tag{116}$$

The electric current $I = \frac{dQ}{dt}$ represents the flow of the electrical engineering domain. This is highly conforming geometry and fixed area.

Uniform velocity, constant electric field, and fixed geometry are assumed in the circuit theory.

The current density j is parallel to the electric field. The relationship between the electric field and the current density defines the resistivity of the material, which is donated by ρ. For many common conducting materials, where electric-fields are not too strong, the resistivity becomes independent of the electric field. This is called Ohm's Law.

$$\rho = \frac{\vec{E}}{\vec{J}} \tag{117}$$

In circuit theory where the wire of length L is made by conductors, a constant uniform current density that passes a constant cross section (A) is assumed. The equation above can be written as

$$\rho = \frac{AV_e}{dL} \tag{118}$$

$$R = \frac{V_e}{I} = \frac{L}{A}\rho[Q^{-1}L^2T^{-3}] \tag{119}$$

A realization of an energy source happens when the charges are enclosed between two points. The electric field in this case is a uniform electric field. A charge does not have to be a point charge; it could be a cloud of charges. For a given distance (r), you can enclose a certain amount of charges. The best way to represent this is by defining the charge surface (charge density). A surface charge is of importance because at the surface of the sphere, one is unable to decipher where charges are. Under the influence of an electric field, the realization of the container is defined as

$$\mathrm{C} = \frac{\vec{D}}{\vec{E}} = \frac{q}{V} = \frac{A}{d}\varepsilon[QL^{-2}T^2]. \tag{120}$$

If Faraday’s and Ampere’s laws are applied, the effort and flow of the magnetic system are introduced.

$$V = -N\frac{d\varphi}{dt}, \tag{121}$$

$$mmf = NI. \tag{122}$$

From equations and gyrator theory, we can conclude that the effort in the magnetic domain is mmf and the flow in the magnetic domain is $\frac{d\varphi}{dt}$. The composite mass in this case is φ

Here, a magnetic flux (φ) is the fundamental physical entity of a magnetic sub-domain, and therefore it is the fluent of magnetic domain.

Flow can be defined in a magnetic domain as the movement of the magnetic flux in a magnetic material in a unit of time. It can be defined as

$$I_m = \frac{d\varphi}{dt}[V] \tag{123}$$

In general terms, effort can be defined as the magneto-motive force (mmf) needed to generate a magnetic current or to produce work in magnetic systems.

As a standard model element, the resistance can be generalized as the quantity that describes the amount of energy released as heat due to the magnetic current in a magnetic material. When the magnetic voltage is applied, the material allows up to a certain degree of the magnetic current; the resistance is a measure of this degree. Its generalized expression is defined as

$$(R_m) = \frac{mmf}{I_m} = \rho_{mag}\frac{L}{A} \tag{124}$$

As a standard model element, the capacitance can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied magneto motive force. Mathematically it is expressed as,

$$C_m = \frac{flux}{mmf} = \mu \frac{A}{L} \tag{125}$$

The equivalent circuit of the electromagnetic domain is shown in Fig. 14 and Fig. 15.

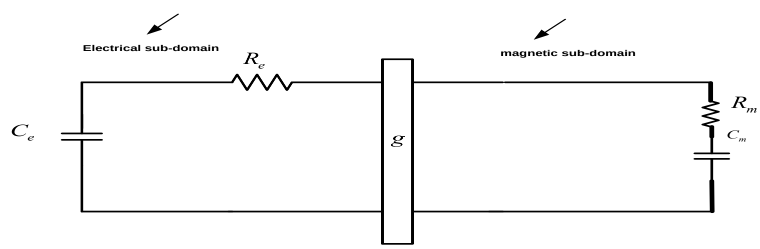

Fig. 14 The equivalent circuit of the electromagnetic domain

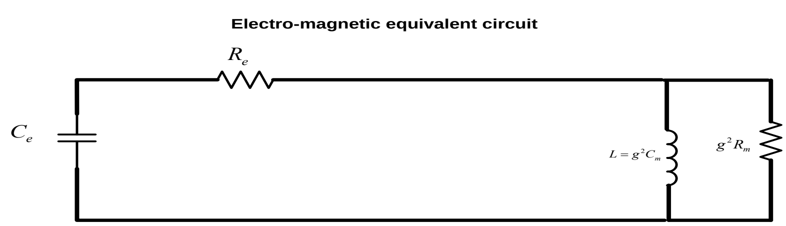

Fig. 15 The simplified equivalent circuit of the electromagnetic domain

The comparison between the electrical and magnetic energy variables are presented in Table 6

Table 6 Energy Dynamics Variables for Electric and Magnetic Domains

Generalization	Electrical	Magnetic
Fluent	Electric charge[Q]	Magnetic flux φ
Flow	Current [A]	$\frac{d\varphi}{dt}[V]$
Effort	Voltage [V]	MMF [A]
Dissipative Element	Resistance [ohm]	Magnetic resistance [ohm^{-1}]
Storage Element	Capacitance [F]	Magnetic capacitance[H]

4.2 Space-Time Domain

In physical systems, mass moves based on different forces, such as gravity, electric, and magnetic forces. In this section, we are going to study the mass dynamic from different types of forces, since the mechanical mass could be coupled with other masses, like charges, fluxes, etc. When two different masses are coupled, a synthetic domain is created.

As mentioned before, the electrical system is used as archetype and we know that energy in electrical domain is defined as

$$W = Q \times V \tag{126}$$

However, we know that energy equation is also defined as

$$W = r \times F \tag{127}$$

As mentioned previously, force is the effort of the space-time (mechanical) domain, and therefore r is the system space (the location of space). System space represents the fluent of the space-time (mechanical) domain. This assumption is based on the energy equations defined in (127) .

Flow can be defined in the space-time (mechanical) as the rate of change of a fluent with respect to time.

$$u = \frac{dr}{dt}\left[\frac{L}{\mathrm{T}}\right] \tag{128}$$

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat due to the current in a space-time domain. When a force is applied, the medium allows up to a certain degree of velocity; the resistance is a measure of this degree. Its generalized expression is defined as

$$(R_{mec}) = \frac{F}{u} \tag{129}$$

Resistance represents the leaking energy in the system in a form of heat or other form of energy. Example of a mechanical resistance is viscosity.

As a standard model element, the capacitance in a mechanical domain can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied force. Mathematically it is expressed as,

$$C_{mec} = \frac{space}{force} = \frac{r}{F}\left[\frac{T^2}{M}\right] \tag{130}$$

An example of a mechanical capacitance is the inverse of a spring constant (K)

If the pattern of Faraday's law is applied, the effort and flow of the co-mechanical system will be defined. From (122), the fluent of co-domain can be represented as follows:

$$\varphi = \int V.dt. \tag{131}$$

Therefore, the fluent of the co-mechanical domain is $p = F.t$, whose momentum is $(p = mv)$.

Flow can be defined in a co-mechanical domain as the movement of the momentum in a medium in a unit of time. It can be defined as

$$I_{co-mec} = \frac{d(mv)}{dt}[N] \tag{132}$$

In general terms, the effort can be defined as co-force $\left[\frac{L}{T}\right]$ needed to generate a co-velocity or to produce work in a co-space-time system.

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat due to the co-velocity in a mechanical material. When a co-force is applied, the material allows up to a certain degree of co-velocity; the resistance is a measure of this degree. Its generalized expression is defined as

$$(R_m) = \frac{co - force}{co - veocity}\left[\frac{T}{M}\right] \tag{133}$$

As a standard model element, a capacitance of co-mechanical domain can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied co-force. Mathematically it is expressed as,

$$C_{co-mech} = \frac{mv}{v}[M] \tag{134}$$

The equivalent circuit of the electromagnetic domain is shown in Fig. 16 and Fig. 17.

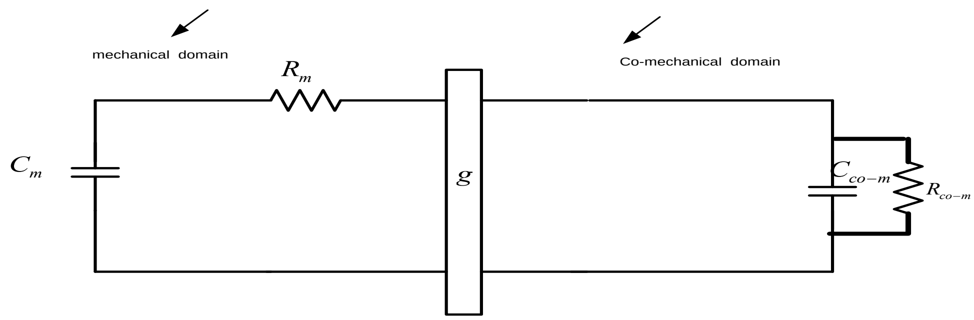

Fig. 16 The equivalent circuit for a space-time domain

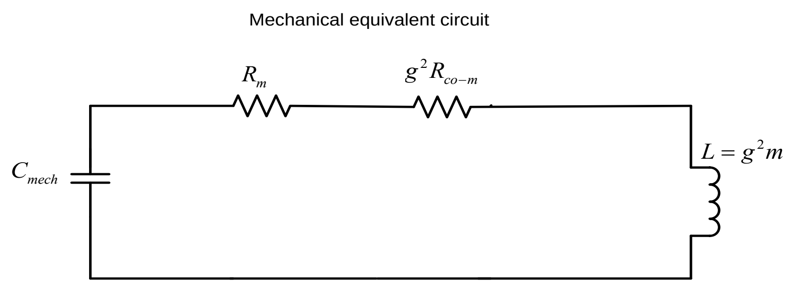

Fig. 17 The simplified equivalent circuit for a space-time domain

Table 7 Energy Variables for Space-Time and Co-Space-Time Domains

Generalization	Mechanical	Co-mechanical
Fluent	Displacement [L]	momentum
Flow	Velocity $[L/T]$	$\frac{dp}{dt}[F]$
Effort	Force [N]	Co-force $[L/T]$
Storage Element	Capacitance $[\frac{T^2}{M}]$	Co-mechanical capacitance[M]

4.3 Rotational Domain

In rotational systems, the fluent is the angle $\theta[rad]$. Angular velocity can be defined in a rotation domain as the rate of change of the angle in a unit of time. It can be defined as

$$\omega = \frac{d\theta}{dt}\left[\frac{rad}{\mathrm{T}}\right] \tag{135}$$

In general terms, the effort can be defined as torque needed to generate an angular velocity or to produce work and in mechanical systems. It is called torque (*N.L*).

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat due to the angular velocity of a mechanical material. The resistance/friction is defined as

$$(R_{R-mec}) = \frac{torque}{anguler\ velocity} \tag{136}$$

As a standard model element, the capacitance can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied torque. Mathematically, it is expressed as

$$C_{mec} = \frac{angle}{torque}\left[\frac{rad}{N.L}\right] \tag{137}$$

The flow can be defined in its co-domain as the movement of the angular (P_ω) momentum with respect to time and can be defined as

$$I_{co-rot} = \frac{d(P_\omega)}{dt}[N] \tag{138}$$

In general terms, the effort can be defined as a co- torque $\left[\frac{rad}{TN.L}\right]$ needed to generate a co-angular velocity or to produce work and in co-rotation systems.

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat due to the co-angular velocity of a mechanical material. When a co-mechanical force is applied, the material allows up to the certain degree of co-mechanical velocity; the resistance is a measure of this degree. Its generalized expression is defined as

$$(R_m) = \frac{co - torque}{co - anguler\ veocity}\left[\frac{rad}{N.L.T}\right] \tag{139}$$

As a standard model element, the co-rotational capacitance can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied co-torque. Mathematically, it is expressed as

$$C_{rm} = \frac{P_\omega}{Co - torque} = moment\ of\ intertal \tag{140}$$

4.4 Hydraulic Domain

A fluent is defined as the fundamental physical entity of a hydraulic system. In hydraulic systems, the state variable is the volume of fluid $\upsilon[L^3]$.

A flow rate is the flow in a hydraulic domain. It can be defined as

$$flow = \frac{d\upsilon}{dt}\left[\frac{L^3}{\mathrm{T}}\right] \tag{141}$$

In general terms, the effort can be defined as pressure needed to generate a flow or to produce work in υ systems. It is called pressure: $\mathrm{P_r}\left[\frac{N}{\mathrm{L}^3}\right]$ $[ML^{-1}T^{-2}]$

As a standard model element, the resistance can be generalized as the quantity that describes the amount of energy released as heat due to the flow in hydraulic systems. The resistance/friction is defined as

$$Dissipative\ element\ \left(R_{hyd}\right) = \frac{pressure}{flow}\left[\frac{ML^{-4}}{T^3}\right] \tag{142}$$

As a standard model element, capacitance can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied pressure. Mathematically, it is expressed as

$$C_{hyd} = \frac{v}{pressure}\left[\frac{L^4T^2}{M}\right] \tag{143}$$

Co-composite state variable is defined as the fundamental physical entity of a co-hydraulic sub-domain. In co-hydraulic systems, the state variable is fluid momentum $(p_h = vm)$, where m is the mass.

The flow can be defined in a co-hydraulic sub-domain as the movement of the fluid momentum $(p_h)$with respect to time and can be defined as

$$I_{co-hyd} = \frac{d(p_h)}{dt}[N] \tag{144}$$

In general terms, the effort can be defined as co- pressure $\left[\frac{v}{T}\right]$needed to generate a co-flow or to produce work and in co-hydraulic systems.

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat due to co-hydraulic flow of a hydraulic system. It is defined as

$$(R_m) = \frac{co - pressure}{co - flow}\left[\frac{T^3}{ML^2}\right] \tag{145}$$

As a standard model element, the co-hydraulic capacitance is generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied co-pressure. Mathematically, it is expressed as

$$C_{co-hyd} = \frac{P_v}{Co - pressure} = mass \tag{146}$$

4.5 Thermal Domain

In this section, the thermal system, as shown in Fig. 18 will be analyzed and investigated. The pattern of the electromagnetic domain will be applied to the thermal domain.

In order to apply the pattern of the electromagnetic domain to thermal systems, new variables should be defined. The first variable is called thermal capacitance.

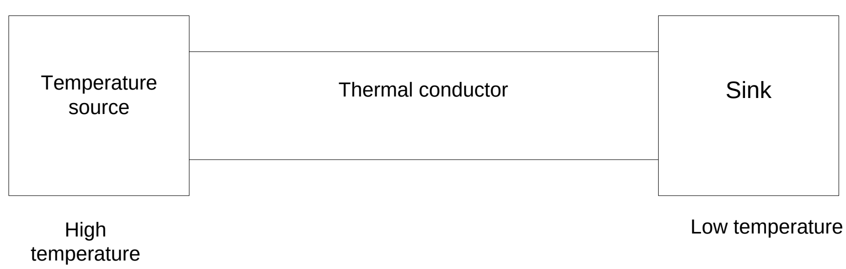

Fig. 18 Two temperature sources are connected through a thermal conductor

In electrical systems, energy that is stored in a capacitor can be calculated as:

$$W = \frac{1}{2}qV \tag{147}$$

From (147), the energy source of electrical systems is a capacitor that sustains charges. By applying the same pattern of electrical systems, the thermal capacitance is defined as an energy source that sustains something. Effort in any energy system is defined as the force that creates flow. No flow of thermal energy occurs if two temperatures are the same. The only way to have flow is when one of the temperature steps. Therefore, effort in thermal systems is temperature. Moreover, thermal energy as defined in the physics books is

$$\Delta W_{th} = \Delta S\ (T) \tag{148}$$

where W_{th} is thermal energy, S is entropy, and T is the temperature. From (147) and (148), it can be noted that entropy is the fluent of the thermal domain. Therefore, a thermal capacitor is defined as the ratio between entropy and temperature.

The energy thermal device is a thermal capacitor that stores entropy. An example of a thermal capacitor is a chunk of iron, since it holds temperature if it is connected to absolute zero. In other words, if an iron is pulled out from liquid hilum and it is heated, it does not dissipate energy. It is similar to an electrical capacitor, when the two plates of a capacitor are separated and charged.

Thermal flow is defined when two thermal capacitors are connected through a thermal conductor, as shown in Fig. 19.

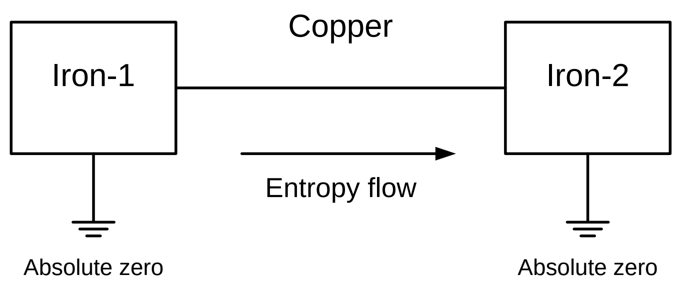

Fig. 19 Two physical thermal capacitors are connected through copper

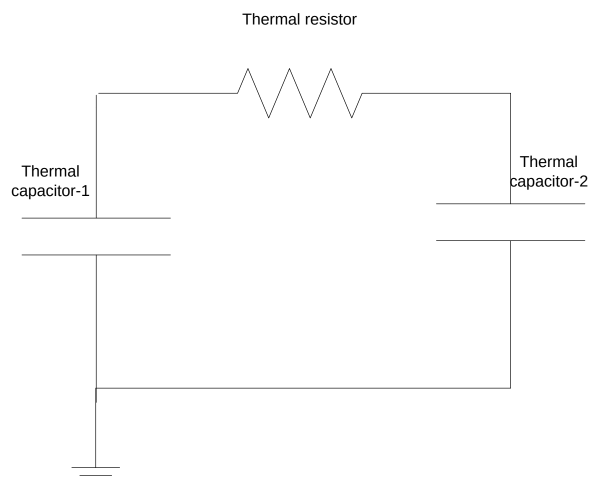

Fig. 20 Two thermal capacitors are connected through a thermal resistor

In electrical systems, when two capacitors are connected to each other, conservation of energy will be violated. A resistor should be added to the system in order to not violate the conservation of law. The analysis of a two-capacitor circuit will be investigated in chapter 6. For this reason a thermal resistor that depends on the material, length, and cross section should be connected between two thermal capacitors, as shown in Fig. 20.

The fluent in thermal systems is entropy $\left[\frac{Joule}{T_\theta}\right]$. Flow can be defined as the movement of entropy in an iron or a medium in a unit of time. It can be defined as

$$I_{th} = \frac{dS_{th}}{dt}\left[\frac{Watt}{\mathrm{T}}\right] \tag{149}$$

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as heat caused by the thermal current in a thermal material. When effort is applied, the material allows up to a certain degree of current; the resistance is a measure of this degree. Its generalized expression is defined as

$$(R_{th}) = \frac{temperature}{thermal\ current}\left[\frac{T^2}{Watt}\right] \tag{150}$$

A thermal resistance's value fundamentally depends on the intrinsic property of the material and its geometry.

$$(R_{th}) = \frac{T_{high} - T_{low}}{I_{th}} = \frac{\rho_{th} l}{A} = \frac{l}{\sigma_{th} A}\left[\frac{T^2}{Watt}\right] \tag{151}$$

where l is the conductor's length, A is the cross sectional area of the conductor, $\rho_{th}\left[\frac{Watt}{T_\theta{}^2 L}\right]$is thermal resistivity of the material, and $\sigma_{th}\left[\frac{T_\theta{}^2 L}{watt}\right]$ is the thermal conductivity of a material.

$$(P_{th}) = I^2{}_{th} R_{th}[watt] \tag{152}$$

Thermal resistance in the conventional model is defined as the ratio of temperature and thermal power (the rate of the heat flow). Mathematically,

$$(R_{th}) = \frac{T_{high} - T_{low}}{power}\left[\frac{T}{Watt}\right] \tag{153}$$

The conventional thermal model is inconsistent with universal power losses of the resistance. In other words,

$$(P_{th}) = I^2{}_{th}R_{th}[watt.T] \neq [watt] \tag{154}$$

As a standard model element, a thermal capacitance can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied temperature. Mathematically, it is expressed as

$$C = \frac{thermal\ charge}{temperature}\left[\frac{Joule}{T^2}\right] \tag{155}$$

A thermal capacitance's value fundamentally depends on the intrinsic property of the material and its geometry.

$$(C_{th}) = \frac{Q_{th}}{T}\left[\frac{Joule}{T^T}\right] = \frac{\varepsilon_{th}A}{l} = \frac{l}{\sigma_{th}A}\left[\frac{T^2}{Watt}\right], \tag{156}$$

where l is the conductor's length, A is the cross sectional area of the conductor, and $\varepsilon_{th}\left[\frac{Joule}{T_\theta{}^2L}\right]$is permittivity of the material.

Thermal capacitance in the conventional model is defined as the ratio of the temperature and thermal power (the rate of the heat flow). Mathematically,

$$(C_{th}) = \frac{energy}{T_{high} - T_{low}}\left[\frac{Joule}{T}\right] \tag{157}$$

A sate variable is defined as the fundamental physical entity of a co-thermal sub-domain. In co-thermal systems, the state variable is thermal flux$[T_\theta.T]$.

Flow can be defined in a thermal of co domain as the movement of the thermal flux in a unit of time. It can be defined as

$$I_{Co-th} = \frac{d\varphi_{th}}{dt}[T] \tag{158}$$

In general terms, effort can be defined as co-temperature ($\frac{Watt}{T}$) needed to generate co-thermal current or to produce work in co-thermal systems.

As a standard model element, resistance can be generalized as the quantity that describes the amount of energy released as a form of energy, such as mechanical energy in a co-thermal system. When a co-temperature is applied, the material allows up to the certain degree of co-thermal current; the resistance is a measure of this degree. Its generalized expression is defined as

$$(R_{co-th}) = \frac{co-temperature}{co-thermal\ current}\left[\frac{Watt}{T^2}\right]. \tag{159}$$

As a standard model element, a capacitance can be generalized as the quantity that measures the amount of energy stored in the regime of work due to an applied co-temperature. Mathematically, it is expressed as

$$C_{co-the} = \frac{thermal\ flux}{co-temperature}\left[\frac{T^2 {T_\theta}^2}{Joule}\right]. \tag{160}$$

Co-thermal capacitance is a new concept that represents a thermal inductance in thermal system.

$$L_{th} = g^2 \frac{\mu_{th} \cdot A}{l}\left[\frac{T^2 {T_\theta}^2}{Joule}\right]. \tag{161}$$

where $\mu_{th}\left[\frac{LT^2 {T_\theta}^2}{Joule}\right]$ is the thermal permittivity of the thermal material.

In the conventional model of a thermal system, there is no such a thermal inductance. However, we propose in this section a thermal inductance to complete the set of the thermal domain.

The complete set of thermal energy dynamics describes the energy dynamics in a thermal domain. The equivalent circuit of the thermal domain is shown in Fig. 21 and Fig. 22.

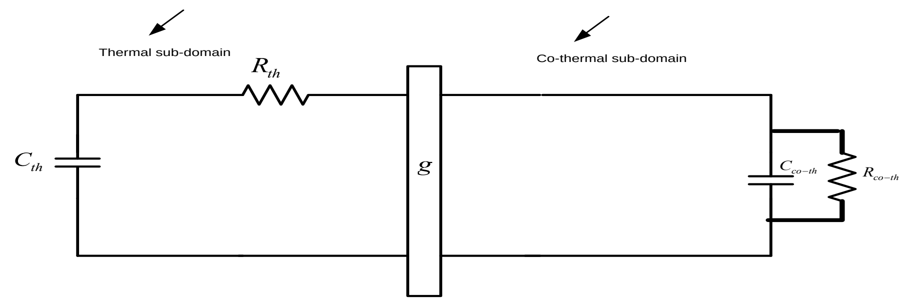

Fig. 21 The equivalent circuit for a thermal domain

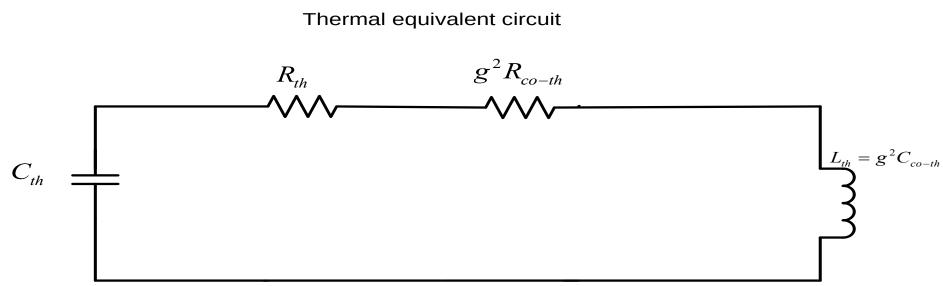

Fig. 22 The simplified equivalent circuit for a co-thermal domain

Table 8 Energy Variables for a Thermal and Co-Thermal Domains.

Generalization	Thermal	Co-thermal
Conserved Quantity	Thermal Charge $[\frac{Joule}{T}]$	Thermal flux [T.t]
Flow	Thermal current $[\frac{Watt}{T}]$	Co-thermal current$[T]$
Effort	Temperature [T]	Co-temperature$[\frac{Watt}{T}]$
Dissipative Element	Thermal resistance $[\frac{T^2}{Watt}]$	Co-thermal resistance$[\frac{Watt}{T^2}]$
Storage Element	Thermal capacitance $[\frac{Joule}{T^2}]$	Co-thermal capacitance$[\frac{t^2 T^2}{Joule}]$

4.5.1 Thermal Inductance

Some papers, like in[37], suggest that the inductance phenomena can be observed in the natural convection process, as described in chapter 2.

According to energy dynamic theory, this is a mixed mode analysis of thermal and mechanical (fluid dynamics) systems. In the mechanical domain, mass is an inductance; it can interact with the capacitance in the thermal domain. Thus, mathematically, it looks like an “LC” or “LRC” network. However, physically, this is not real.

In fact, the thermal resistance is defined incorrectly and its dimensions do not work consistently with the other domains. For example, (I^2R) of a thermal domain does not yield power dimension. So the entire mathematical construct in paper may be artificial modeling without a basis in physics. We are interested in defining the properties of the medium (R, L, C, I, V, W, P, etc.) correctly and consistently with all other domains, the dimensions of energy and power, which must stay the same in all media.

The thermal inductance as described in [37] does not come from gyration when power crosses the thermal domain into the mechanical domain. Furthermore, a double gyration is unlikely. What happens is that the mechanical mass (mechanical inductance) shows up as inductance in the thermal domain.

In general, when power crosses a one domain to another, a lossless gyration occurs. This means that parameters of one domain are seen as their dual in the other domain. Thus, the mass (mechanical inductance) on the shaft of an electro-mechanical power converter (motor) looks like capacitance in the thermal domain and can, in fact, oscillate with the inductance on the thermal side.

5 WAVE PROPAGATIONS

5.1 Transmission Line Equivalent Circuit for Electromagnetic Domain

In this section, transmission line equations will be generalized for various domains. The main concept of the proposed theory is that energy located in a domain travels in a power form to another domain, while maintaining its unit (Joule).

In each domain, there are two complementary state variables, which are needed for writing transmission line equations of any domain. The patterns of the transmission line (T.L) equations are based on the Maxwell equations. In other words, electric and magnetic fields are replaced by voltage and current for simplicity.

Capacitance, inductance, and resistance should be in per unit length for the electromagnetic transmission line analysis in order to completely describe the energy dynamic within electrical and magnetic domains. Energy travels in space and time, so voltage and current should be a function of time and space [74-77].

The pattern of the electromagnetic transmission line equations will be applied to other energy systems in order to describe their dynamics, predict behaviors, and explain observations.

An electromagnetic transmission line can be described by its line variables:

1. Resistance-R (resistance per unit length) Ω/l
2. Inductance-L (inductance per unit length) H/l
3. Capacitance-C (capacitance per unit length) F/l
4. Conductors-G (conductors per unit length) S/l

These variables are distributed along the line (not lumped). Fig. 23 shows the equivalent T.L for an EM domain for one increment Δx. G is due to the loss y dielectric between two conductors. If $\sigma = 0$, then G=0. R is the ac resistance of the conductors. If $\sigma = \infty$, then R=zero (perfect conductors).

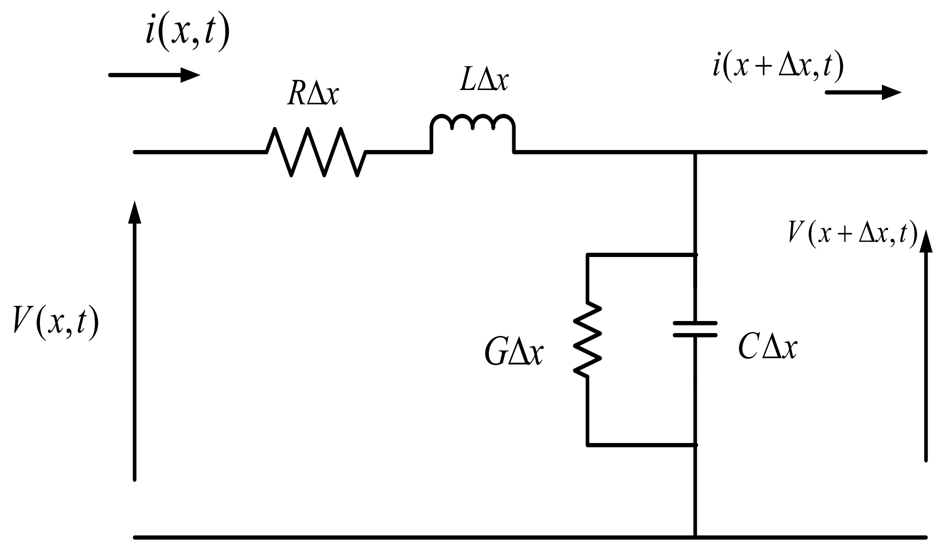

Fig. 23 Equivalent circuit for an electromagnetic transmission line

C is the capacitance between 2 conductors, and L is the external inductance caused by the magnetic flux around the wire. For any transmission line, the wave speed is defined as $up = \sqrt{\mu\varepsilon}\left[\frac{l}{t}\right]$. By applying Kirchhoff Voltage Law (KVL) and Kirchhoff Current Law (KCL) to the transmission line, the equations can be written as

$$V(x,t) = R\,\Delta x\, I(x,t) + L\,\Delta x\,\frac{\partial I}{\partial x} + V(x+\Delta x,t) - \frac{V(x+\Delta x,t)-V(x,t)}{\Delta x}, \tag{162}$$

$$V(x,t) = R\,I + L\,\frac{\partial I}{\partial t}, \text{ as } \Delta x \to 0\ yeids \tag{163}$$

$$-\frac{\partial V}{\partial x} = R\, I + L\, \frac{\partial I}{\partial t}, \tag{164}$$

$$I(x,t) = I(x+\Delta x, t) + G\,\Delta x\;\; V(x+\Delta x, t) + C\,\Delta x \frac{\partial V}{\partial t}, \text{ as } \Delta x \to 0\; yeids, \tag{165}$$

$$-\frac{\partial i}{\partial x} = G\, V + C\, \frac{\partial V}{\partial t}. \tag{166}$$

General transmission line equations for EM domain are determined by the equations (164) and (166), and therefore, wave equations can be written as

$$\frac{\partial^2 V_s}{\partial x^2} = \gamma^2 V_s, \tag{167}$$

$$\frac{\partial^2 I_s}{\partial x^2} = \gamma^2 I_s, \tag{168}$$

where $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$, $\omega = 2\pi f, and\ f$ is the frequency.

5.2 Mechanical Wave

In this section, a comparison between the conventional rope wave equations and the pattern of electromagnetic transmission line equations that describe the dynamics of the rope will be introduced.

5.2.1 Conventional Rope Equations

Rope, as shown in Fig. 24, has a length of dx, a tension (T) and mass per unit length μ. The tension in both sides is assumed to be the same when the displacement is not high. In order to make this assumption reasonable, the angle should also be very small. This assumption is reasonable because the rope equations describe the motion in y-direction. Therefore, the motion in x-direction will not matter.

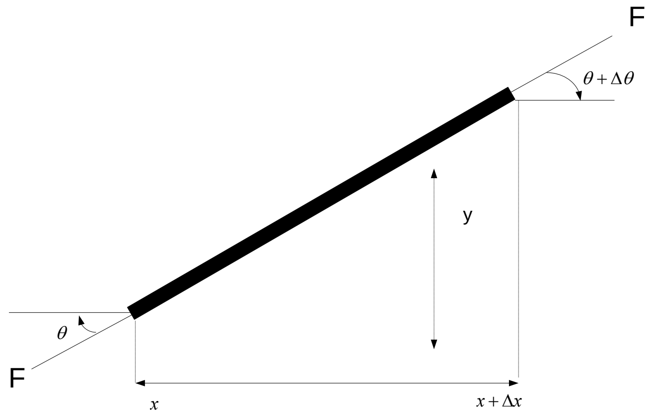

Fig. 24 A stretched rope under the force F

The force in y-direction can be written as

$$F_y = -Tsin(\theta) + Tsin(\theta + \Delta\theta). \quad (169)$$

Since the angle is small, the approximation of $sin(\theta) \sim \theta$ holds, and therefore, (169) can be rewritten as

$$F_y = T\Delta\theta. \quad (170)$$

By applying the second newton's law

$$(dm)\ddot{y} = T\Delta\theta, \quad (171)$$

where $dm = (\Delta x)\mu$.

As seen in Fig. 24 , the tangent of θ can be written as

$$\tan(\theta) = \frac{\partial y}{\partial x}. \quad (172)$$

By taking the first derivative of (172) with respect to x leads to

$$\frac{1}{\cos^2\theta}\frac{d\theta}{dx} = \frac{\partial^2 y}{\partial^2 x}. \quad (173)$$

Substitution of (173 into (171) results the following wave equation.

$$\frac{\partial^2 y}{\partial^2 t} = \frac{T}{\mu}\frac{\partial^2 y}{\partial^2 x}, \qquad (174)$$

where $\sqrt{\frac{T}{\mu}}$ represents the velocity of the rope wave.

5.2.2 Mechanical Maxwell's Equations for an Elastic Rope

The pattern of Electric transmission line equations will be applied to an elastic rope. Fig. 26 shows the equivalent T.L for an EM domain for an increment length Δx of a mechanical T.L that describes the rope wave.

The mechanical energy variables are defined in per unit length. Energy travels in space and time, so force and velocity should be a function of time and space.

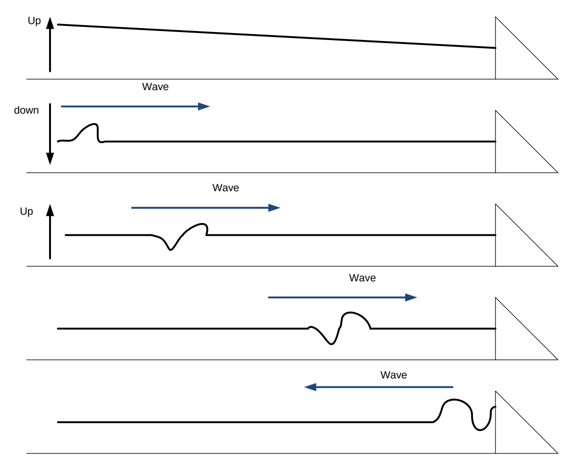

Fig. 25 A physical rope wave

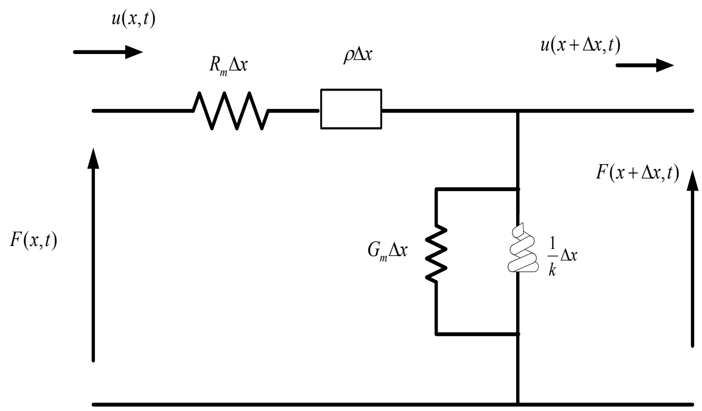

Fig. 26 An equivalent transmission line for the rope

A transmission line can be described by its line parameter:

1. Resistance-R (resistance per unit length) mt^{-3}/l

2. Mass-ρ (co-mechanical inductance per unit length) m/l

3. Spring constant-1/k (mechanical capacitance per unit length) t^2/lm

4. Conductors-G (conductors per unit length) t^3/ml

These parameters are distributed along the line (not lumped). If $\sigma = 0$, then G=0. R is the ac mechanical resistance of the conductors. If $\sigma = \infty$, then R=zero. For a rope transmission line, the wave speed is defined as $up = \sqrt{\frac{\rho}{k}}\left[\frac{L}{T}\right]$.

By applying Kirchhoff Voltage Law (KVL) and Kirchhoff Current Law (KCL) to the transmission line, the equations can be written as

$$F(x,t) = R_m \, \Delta x \, u(x,t) + \rho \, \Delta x \, \frac{\partial u}{\partial x} + F(x+\Delta x, t) - \frac{F(x+\Delta x,t) - F(x,t)}{\Delta x}, \tag{175}$$

$$F(x,t) = R\, u + L \, \frac{\partial u}{\partial t}, \tag{176}$$

$$-\frac{\partial F}{\partial x} = R_m u + \rho \, \frac{\partial u}{\partial t}, \tag{177}$$

$$u(x,t) = u(x+\Delta x, t) + G_m \, \Delta x \;\; F(x+\Delta x, t) + \frac{1}{k} \, \Delta x \frac{\partial F}{\partial t} \text{ as } \Delta x \to 0 \; yeids, \tag{178}$$

$$-\frac{\partial u}{\partial x} = G_m \, F + \frac{1}{k} \, \frac{\partial F}{\partial t}. \tag{179}$$

General transmission line equations for a mechanical rope domain are determined by the equations (177) and (179), and therefore, wave equations can be written as

$$\frac{\partial^2 F_s}{\partial x^2} = \gamma^2 F_s, \tag{180}$$

$$\frac{\partial^2 u_s}{\partial x^2} = \gamma^2 u_s, \tag{181}$$

where $\gamma = \sqrt{(R_m + j\omega\rho)\left(G_m + j\omega \frac{1}{k}\right)}$, $\omega = 2\pi f, and\ f$ is the frequency.

As seen, the derivation in the conventional theory is based certain assumptions: the small angle of θ. Also, the conventional wave equation is only valid for a small amplitude oscillation of the rope. However, the proposed equations can describe the rope equations under any value of θ and is also valid for any amplitude oscillation of the rope.

5.3 Thermal Wave

In this section, thermal transmission line equations will be provided for the thermal domain. Fig. 27 shows an iron rod in connection between two different temperature sources, namely T_1 and T_2.

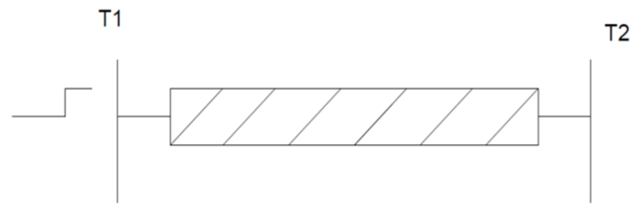

Fig. 27 Two temperature sources connected to an iron rod

In order to write the transmission line equations for the thermal structure, a topology of the thermal transmission line has to be determined through short and open short circuit tests to show how thermal variables are connected.

Let's assume that the transmission occurs in one way and let's ground the second terminal (T_2=0). If we step the temperature in the right side to T_1, the temperature profile will behave as shown in Fig. 28. Several observations occur when the short and open circuit tests have been performed.

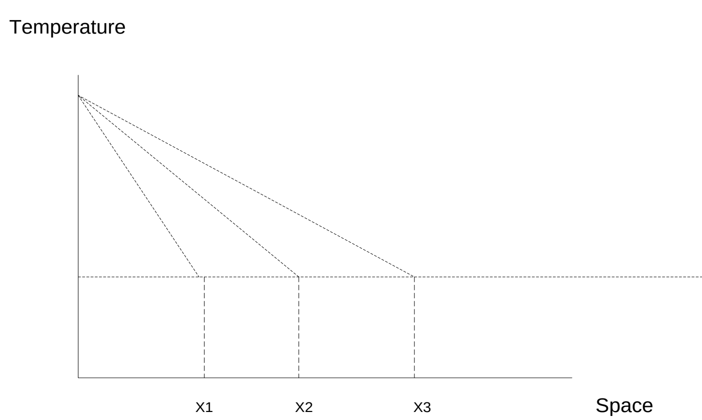

Fig. 28 Temperate profile inside a rod

If the topology is "RLC series" there will be no thermal current and therefore no heat transfer occurs. However, we know that when the temperature of the source increases, heat transfers to the lower temperature. This means the topology of "RLC series" is not the right one.

If the topology of RLC circuit (R and L are in series and C is in parallel). The temperature rises slowly, when it increases due to the effect of the inductance. Also, the temperature drops across the medium as shown in Fig. 28. These observations do not contradict the thermal experiments that have been done in the literature. The only modification we will have for this topology is we need to have at least two steps, because the capacitor sits next to the output. In other words, if the temperature is fixed, we will not get the capacitor effects. We have to leave one capacitor in the middle for the wave to pass through it. Whether the thermal wave oscillates or not, it depends on the damping ratio and we believe that the wave is over damped.

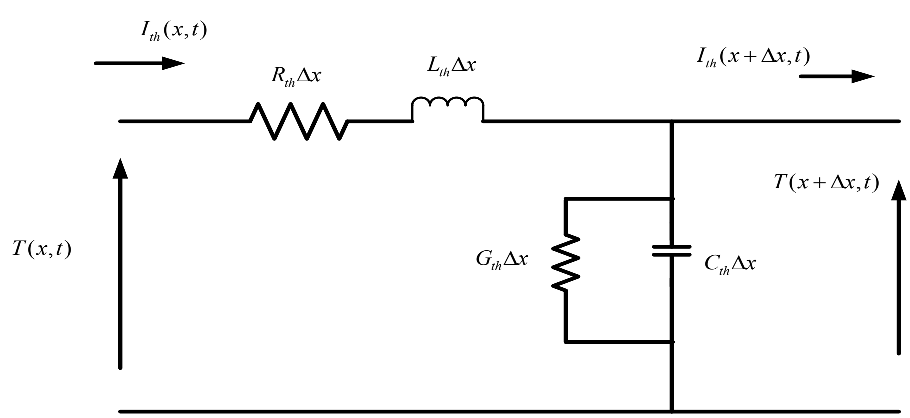

Fig. 29 An equivalent circuit for the thermal transmission line

A transmission line can be described by its line parameter:

1. Thermal resistance (resistance per unit length) $\mathrm{T}^2/_{Wl}$

2. Thermal inductance (co-mechanical capacitance per unit length) $\frac{\mathrm{t}^2 T^2}{Joule\ l}$

3. Thermal capacitance (thermal capacitance per unit length) Joule/lT^2

4. Conductors-G (conductors per unit length) $\mathrm{W}/_{T^2 l}$

These parameters are distributed along the line (not lumped)

$If\,\sigma = \infty$, then R=zero. For a thermal transmission line, the wave speed is defined as $up = \sqrt{L_{th}C_{th}}\left[\frac{L}{T}\right]$.

By applying Kirchhoff Voltage Law (KVL) and Kirchhoff Current Law (KCL) to the transmission line, the equations can be written as

$$T(x,t) = R_{th}\,\Delta x\, I_{th}(x,t) + C_{th}\,\Delta x\,\frac{\partial I_{th}}{\partial x} + T(x+\Delta x,t), \tag{182}$$

$$T(x,t) = -\frac{T(x+\Delta x,t) - T(x,t)}{\Delta x}, \text{ as } \Delta x \to 0\ yeids \tag{183}$$

$$-\frac{\partial T}{\partial x} = R_{th} I_{th} + L_{th}\,\frac{\partial I_{th}}{\partial t}, \tag{184}$$

$$I_{th}(x,t) = I_{th}(x+\Delta x,t) + G_{th}\,\Delta x\ \ T(x+\Delta x,t) + C_{th}\,\Delta x\frac{\partial T}{\partial t}, \tag{185}$$

$$-\frac{\partial I_{th}}{\partial x} = G_{th}\,T + C_{th}\,\frac{\partial T}{\partial t}. \tag{186}$$

General transmission line equations for a mechanical rope domain are determined by the equations (184) and (186), and therefore, wave equations can be written as

$$\frac{\partial^2 T_s}{\partial x^2} = \gamma^2 T_s, \tag{187}$$

$$\frac{\partial^2 I_{th-s}}{\partial x^2} = \gamma^2 I_{th}, \tag{188}$$

where $\gamma = \sqrt{(R_{th} + j\omega L_{th})(G_{th} + j\omega C_{th})}$, $\omega = 2\pi f, and\ f$ is the frequency.

6 CASE STUDIES FOR GENERALIZED ENERGY DYNAMICS

In this section, some applications and examples are introduced to show the importance and powerful of the proposed theory. We examine some physical and engineering examples and show that these examples can be easily solved without any needs for some concepts, like the co-energy concept. We will also show how the math in the proposed theory is simple. We used the same concept, energy patterns, and equations to solve various applications and problems. Lastly, comparisons between the current method and the proposed method are also introduced.

6.1 Transformers

The transformer, as shown below, has two windings: primary and secondary. Each winding has a certain number of turns N_P and N_S, respectively. From the physics standpoint, the relationship between primary and secondary are determined by the number of turns: N_P and N_s [78]. Mathematically,

$$\frac{V_1}{V_2} = \frac{N_P}{N_S}. \tag{189}$$

$$\frac{I_1}{I_2} = \frac{N_S}{N_P}. \tag{190}$$

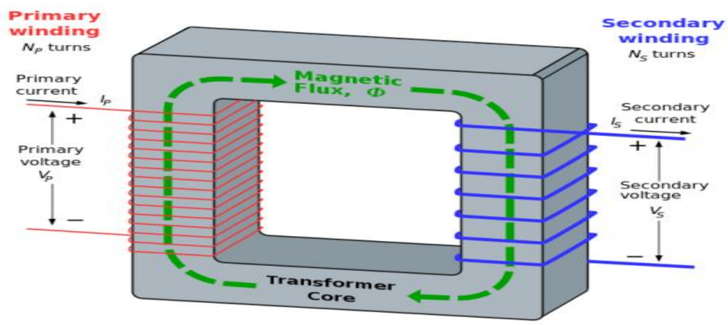

Fig. 30 An electric transformer [78]

The concept of a gyrator will be used to show the relationship between primary and secondary. In fact, the transformers have two sides; each side has one gyrator that is responsible for gyrating energy from an electrical side to a magnetic side. As explained before, energy in one domain is stationary and cannot be dynamic unless it goes to another domain[52]. In other words, the transformer is not a fundamental device. Transformers can be built using two gyrators, as shown below.

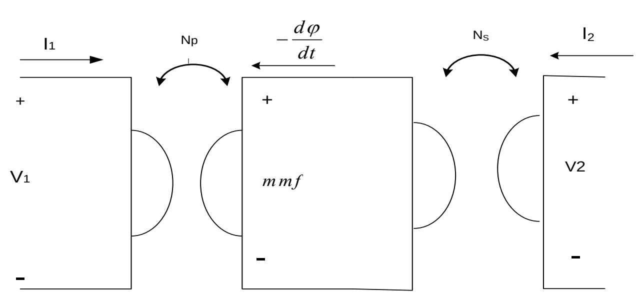

Fig. 31 The gyrator model for an electric transformer

$$V1 = -N_p \frac{d\varphi}{dt}, \tag{191}$$

$$mmf = -N_p I_1. \tag{192}$$

$$V2 = -N_s \frac{d\varphi}{dt}, \tag{193}$$

$$mmf = -N_s I_1. \tag{194}$$

From the equations above, we can derive (189) and (190). This pattern does not only apply for transformers. It also applies for gears, levers, pulley system, etc.

6.2 Equivalent Circuit for Magnetic Model

The reluctance model has been adapted to model the magnetic core. Several models also have been proposed to explain some physical behaviors of the magnetic model, like a hysterics model, etc. In this section, three common models will be presented in this section.

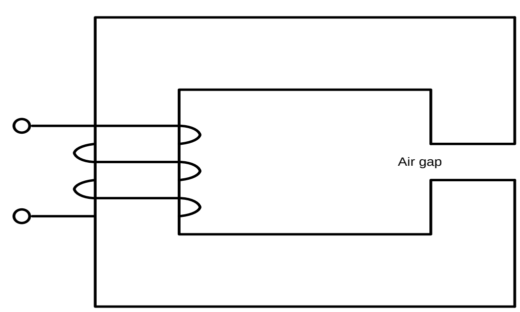

Fig. 32 A magnetic core

6.2.1 Reluctance-Resistance Model

This model shows that the magneto-motive force is analogous to voltage, and magnetic flux is analogous to current. By applying the Ohm's law, $R = \frac{V}{I}$, it can be concluded that reluctance $\Re$ can be defined as follows $\Re = \frac{F}{\varphi}$. Since reluctance is analogous to electrical resistance, it depends on the dimensions and intrinsic properties of the material. Mathematically, reluctance can be defined as

$$\Re = \frac{l}{\mu A} \tag{195}$$

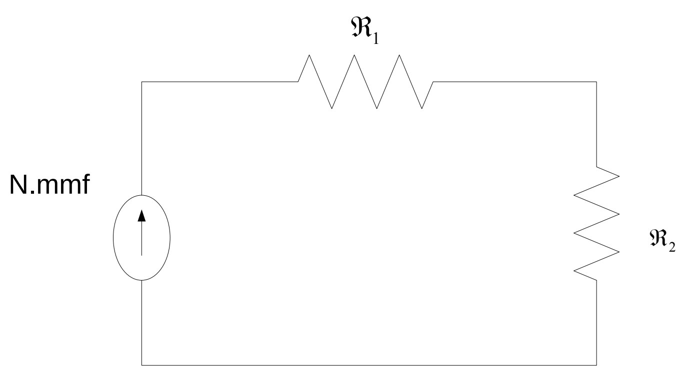

Fig. 33 The reluctance model for a magnetic core

Resistance is a measure of how much energy can be dissipated as heat while current flows in the material. However, in magnetic circuits the reluctance is a measure of magnetic energy storage rather than a measure of magnetic energy dissipation. In other words, magnetic losses cannot be calculated using an analogy of Joules law as in electric circuits. That is,

$$P_e = I^2 R, \tag{196}$$

$$P_m \neq \varphi^2 \mathcal{R} \tag{197}$$

One of the reasons why the reluctance model has been successfully used for so long is that it is a quasi-static model. At low frequencies, the magnetic material shows almost zero heat losses, and the reluctance model represents quite accurately the material's behavior under this condition. However, when alternating currents at medium or high frequency excite the magnetic material, heat losses are more relevant and the reluctance model becomes inconsistent. Consequently, other methods are applied in order to calculate the magnetic losses. For instance, hysteresis losses, which are heat losses resulting from the tendency of the material to oppose a change in magnetism, can be calculated using the area of the hysteresis loop.

6.2.2 Power Invariant Magnetic Model

The Power invariant magnetic model is one of the innovative approaches that are based on the gyrator theory. Our proposed theory is based on this approach. This model, however, has some drawbacks. For example, the magnetic inductance is not necessary to describe the energy behavior within the electromagnetic domain, as explained in chapter 3. In other words, power invariant magnetic model has a redundant quantity [42].

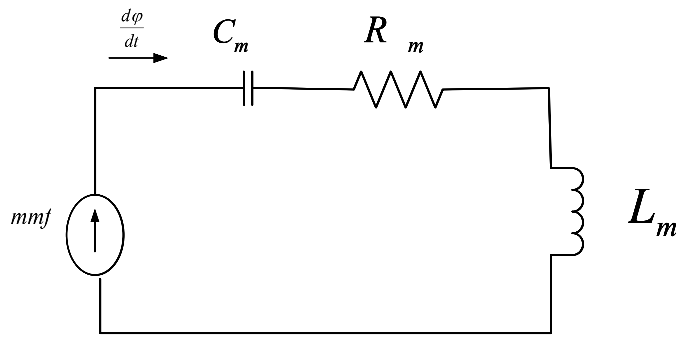

Fig. 34 Power-invariant magnetic model

6.2.3 *Energy Dynamic Model*

In many cases of practical interest, the magnetic and electrical circuits have to interact to each other, so it is very important to analyze the system as one domain, such as electromagnetic domain. Energy dynamic model is the only model that allows us to do so. Also, it brings some insights to simulations, magnetic components for power electronics applications, and magneto-mechanical devices. In addition to these, this model also handles magnetic losses and holds power loss universality.

Two different magnetic capacitors exist in the iron core: the iron core and the air gap. These capacitors are defined as

$$C_{iron} = \frac{A\mu_0 . \mu_r}{l}, \tag{198}$$

$$C_{ag} = \frac{A\mu_0}{l}, \tag{199}$$

The capacitance of the air-gap is dominant since the magnetic permeability of the core is greater than that in the air.

In order to determine if a magnetic resistor is in series or in parallel with a magnetic capacitor, some short and open circuit tests have to be performed. If we open the circuit in the electrical side, we will have a short circuit in a magnetic side, meaning mmf=0. If a magnetic resistance and a magnetic capacitance are in series, the flux will decay with a certain time constant. This case can be observed. However, when the magnetic resistor is in parallel with the magnetic capacitance, the flux will disappear instantly with a big pulse of current. This cannot be observed, and therefore, they are in series

Furthermore, a magnetic capacitor represents an inductor in the electrical side. We know that if the electrical side is shorted (the voltage is zero), the current will be trapped in an inductor, ignoring the galvanic resistant. The only way to achieve that is when the inductor is in parallel with a resistor, since the current will decay with a certain time constant if the inductor and the resistor are connected in series.

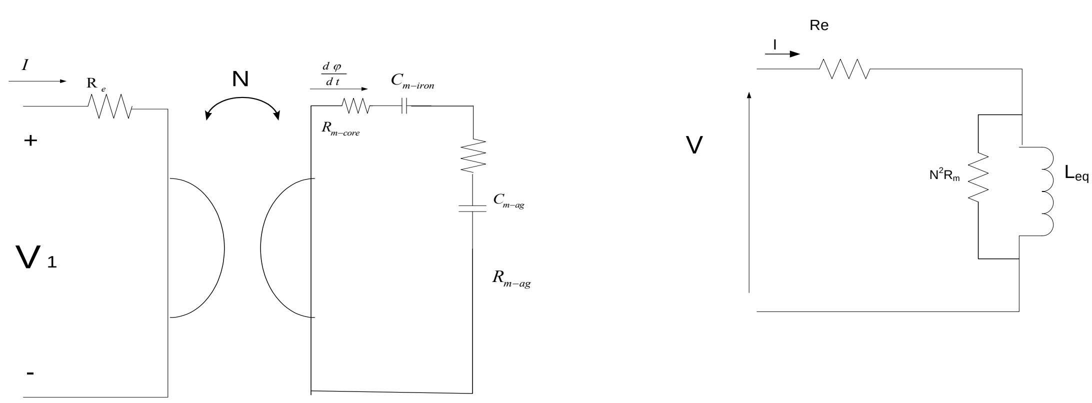

Fig. 35 The equivalent circuit of an air-gapped magnetic core

Fig. 35 shows the equivalent circuit of an air gapped magnetic core. From Fig. 35, the voltage in the electrical side and the equivalent inductance of magnetic capacitors can be written as

$$V = IR + N\frac{d\varphi}{dt}. \tag{200}$$

$$L_{eq} = N^2.\frac{C_{iron}.C_{ag}}{C_{iron}.C_{ag}}. \tag{201}$$

6.3 Superconductivity

Our theory also predicts the superconductivity phenomenon, in which the electrical resistance goes to zero at a certain temperature in certain material. Superconductivity has many applications, such as MRI. The resistor relationship with temperature is shown in the figure below[79-81].

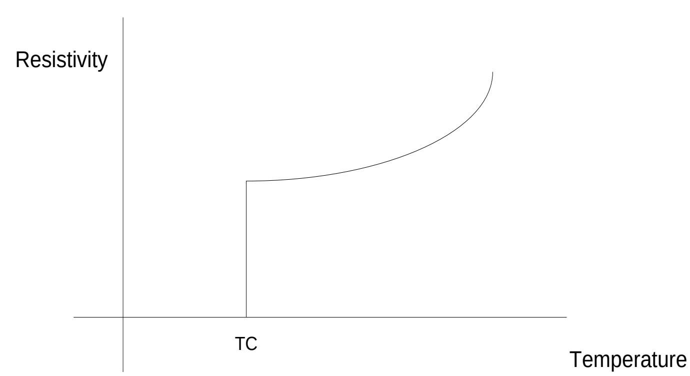

Fig. 36 Relationship between temperature and resistivity

The critical temperature Tc is defined as the temperature at which the resistance starts increasing as temperature value increases. The proposed theory predicts superconductivity phenomena; when the temperature is low, the entropy of the medium is stationary, and therefore, the thermal current is zero. In other words, there is no exporting thermal system into the electrical side. Mathematically,

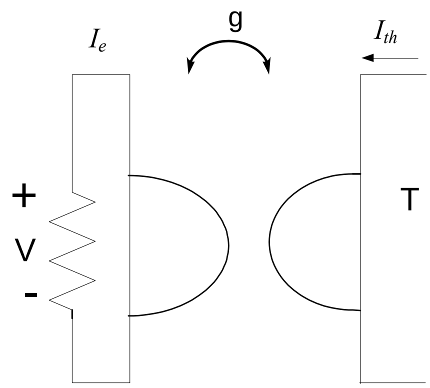

Fig. 37 Energy dynamic equivalent circuit for superconductivity

$$V_e = GI_{th} \tag{202}$$

$$T = GI_e \tag{203}$$

where G is a gyration factor.

According to the energy dynamic theory, resistance's value becomes zero at low temperature. According to ohm's low, when the resistance is zero, there is no power loss and the current flows forever; even if there is no battery or other power sources.

The conventional analysis of superconductivity states that when electrons travel through a cable, electronics travel through atoms (copper atoms). Electrons constantly hit atoms and when atoms agitate each other, they vibrate and transfer energy in the form of heat. The minimum energy (cooper pair) required to break the bonds is 0.001 eV. According to Boltzmann's constant (K)

$$E = KT \tag{204}$$

If the temperature is 10K, the energy will be less than 0.0001 ev and therefore, the bond will not break.

6.4 Carnot Efficiency

Carnot's theorem states " No engine operating between two heat reservoirs can be more efficient than a Carnot engine operating between those same reservoirs" [82].

Our theory establishes an analogy between all energy systems. In other words, Carnot efficiency not only exists in electrical systems, but also in all other energy systems. Carnot efficiency is approved using the proposed theory, as will be shown in this section.

Suppose they are two DC voltage sources, where V1 is greater than V2 and they are connected through a resistor. In electrical systems, power that is being delivered from voltage sources 1&2 are defined as follows.

$$P1 = V_1 I, \qquad P2 = V_2 I. \tag{205}$$

Energy source is usually non-ideal, and therefore a little resistance should be added to the system. Mathematically,

$$P_R = V_1 I - V_2 I - I^2 R_{loss}, \tag{206}$$

$$\eta(I) = \frac{V_1 I - V_2 I - I^2 R_{loss}}{V_1 I} = \frac{V_1 - V_2 - I R_{loss}}{V_1}. \tag{207}$$

$$\eta(I)' = \frac{R_{loss}}{V_1} = 0. R_{loss} = 0 \ . \tag{208}$$

Subtitle R_{loss} to the previous equation,

$$\eta(I) = 1 - \frac{V2}{V1}. \tag{209}$$

In Thermal systems, the equations can be written as follows:

$$P_{Rth} = T_1 I_{th} - T_2 I_{TH} - I^2{}_{th} R_{loss}, \tag{210}$$

$$\eta(I) = \frac{T_1 I_{th} - T_2 I_{th} - I^2{}_{th} R_{loss}}{TI} = \frac{T_1 - T_2 - I_{th} R_{loss}}{T_1}, \tag{211}$$

$$\eta(I)' = \frac{R_{loss}}{T_1} = 0, meaning\ R_{loss} = 0 \ . \tag{212}$$

Subtitle R_{loss} to the previous equation,

$$\eta(I) = 1 - \frac{T2}{T1}. \tag{213}$$

6.5 Carnot Cycle

In this section, we discuss the Carnot cycle from an electrical point view. In other words, a dynamic electrical model for a Carnot cycle will be discussed and showed that the Carnot cycle also exits in any energy systems and could be interpreted easily in electrical systems. A Carnot cycle in thermodynamic systems involves two different energy systems, namely mechanical and thermal systems [83, 84]. Our dynamical model involves electrical and mechanical systems.

The figure below shows the Carnot cycle and how the pressure and volume affect temperature and heat. The Carnot cycle has two different states or processes: isothermal and adiabatic states. An isothermal process is a change of the system, due to the exchange of heat when the system is in contact with the outside. This process occurs very slowly to maintain a constant temperature [85]. The second process is an adiabatic process, which represents a change of the system, due to the change of temperature.

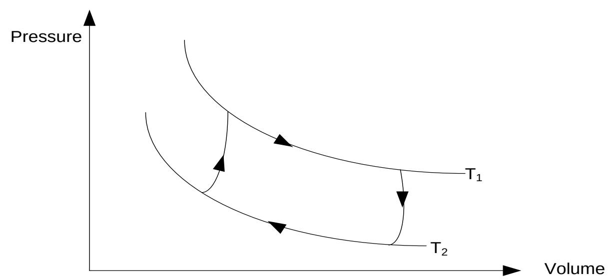

Fig. 38 Carnot cycle on a P-V diagram

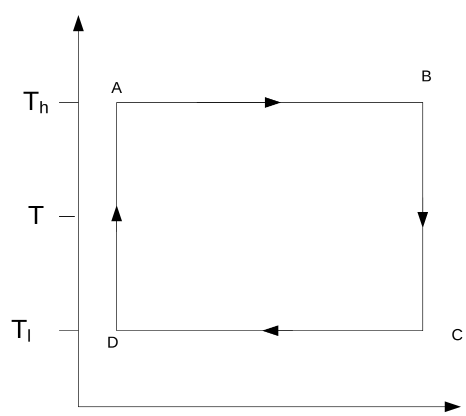

Fig. 39 Carnot cycle on a heat engine

The dynamical electrical model for Carnot efficiency is shown in Fig. 40. The movable capacitor is attached to the string through a fixed pulley. When the displacement is created, work is provided to an electrical system and vice versa.

The process can be summarized as follows:

1. The capacitor is initially charged up to charge q_1.
2. When a movable plate is pulled, the capacitance's value decreases and voltage increases until it reaches V_1.
3. Once the voltage across the capacitor reaches V1, the switch S1 is closed and voltage is equal to $V1$ ($= q_1/C_1$). The voltage across the capacitor remains constant.
4. When the separation of plates is decreased, charges also increase to q2 under a constant voltage.
5. When switch S1 is opened, the separation of the plate decreases, and the voltage across the capacitor decreases. The switch S2 is closed when the potential of the movable plate is equal to $V2$ ($= q2/C2$).
6. When the capacitor is pulled, increasing the separation of the plates, the voltage of the capacitor remains constant. The switch S2 is opened when the amount of displacement charge on the capacitor decreases to q1, and therefore the amount of the displacement charge output is equal to that of the displacement charge input.

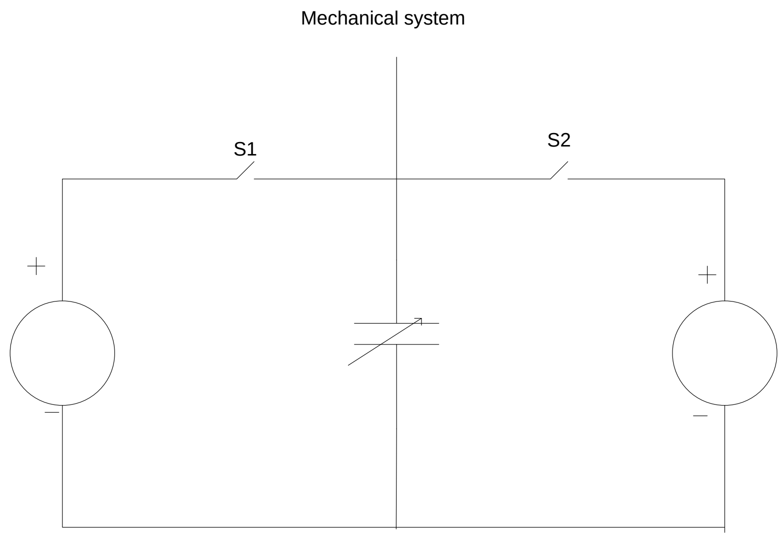

Fig. 40 Electrical equivalent circuit for the Carnot cycle

6.6 Two-Capacitor Problem

6.6.1 Conventional Model of Two Capacitor Circuit

A common problem in the two-capacitor circuit is that the conservation of energy and charge are violated when two capacitors are connected to each other without resistor. However, this problem has been solved in [86] . The conclusion drawn in [86] was that the conservation of energy was violated since there is no physical mechanism for energy dissipation. In other words, when no current flows in the circuit, the total charges in the circuit are split equally between two capacitors. When energy is calculated, there is a missing energy that cannot be justified. Therefore, that energy has to be dissipated through a resistor. This can be shown through simple energy calculations. Suppose we have two identical capacitors: one has q charges, and the other has a zero charge, and they are connected together, as shown in Fig. 41.

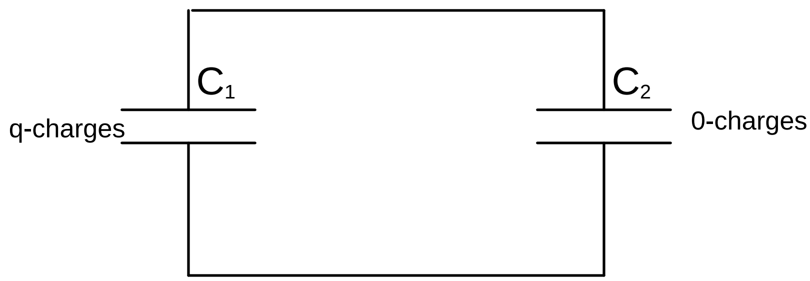

Fig. 41 Two capacitors are connected without a resistor

Initially, the energy stored in C_1 is $W = \frac{q^2}{C}$, and the energy stored in the C_2 is zero. The total energy stored in the system is $W = \frac{q^2}{C}$. Once these capacitors are connected, the total charges will split equally, due to the fact that the capacitors are identical. The energy in each capacitor is $W_{C1} = W_{C2} = \frac{q^2}{4C}$. The total energy after connecting the capacitors is $W = W_{C1} + W_{C2} = \frac{q^2}{2C}$. This violates the conservation of energy since the total energy before connecting two capacitors was $W = \frac{q^2}{C}$.

Moreover, the RC circuit that solves the conservation of energy problem cannot be realistic due to discontinuity; the current steps at no time and that cannot be happened physically. In order to solve this problem, an inductance has to be added to solve the discontinuity problem. In short, when energy flows between two capacitors, resistance and inductance should be defined. Fig. 42 represents the transient response for the two-capacitor circuit for two cases: inductive and non-inductive cases.

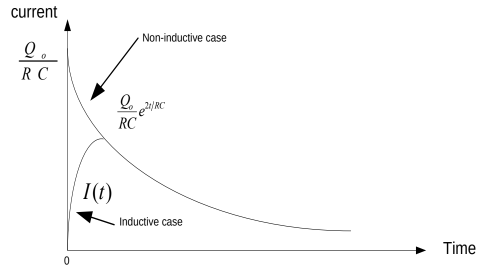

Fig. 42 Transient response for the two-capacitor circuit

In short, during the transient, the voltage across each capacitor is not equal, so the current is not zero. When the current goes through a resistor, the power loss is generated, until the final voltage is reached. The energy loss is generated after the charge transferred. In transient, the movement the electric charge is described by the following equations:

$$\frac{1}{C1}\int i(t)dt + \frac{q_o}{C1} = \frac{1}{C2}\int i(t).dt + iR, \tag{214}$$

$$i(t) = \left(\frac{q_o}{RC}\right)e^{-\left(\frac{-2t}{RC}\right)};\ C1 = C2. \tag{215}$$

The equations above represent the behavior of the C-R-C circuit without inductive effects. This assumption is valid when the circuit is heavily over-damped; a capacitive time constant will be greater than an inductive time constant. If the circuit is not heavily damped, the model RC will not be appropriate.

6.6.2 *The Energy Dynamic Model for Two-Capacitor Circuit*

The energy dynamics theory states that when two energy sources (represented by two capacitors) communicated with each other, resistance and inductance should exist, as shown in Fig. 43.

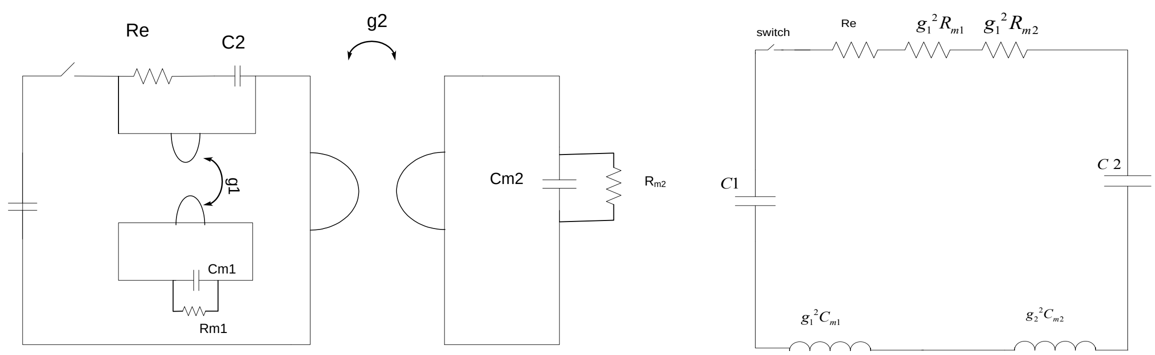

Fig. 43 Energy dynamics model for a two-capacitor circuit

6.6.3 *The Energy Dynamic Model for Heat Transfer*

The energy dynamics model shows how the heat transfer occurs in a thermal system. Fig. 44 shows a thermal system, where two thermal capacitors are connected through thermal resistors and inductors.

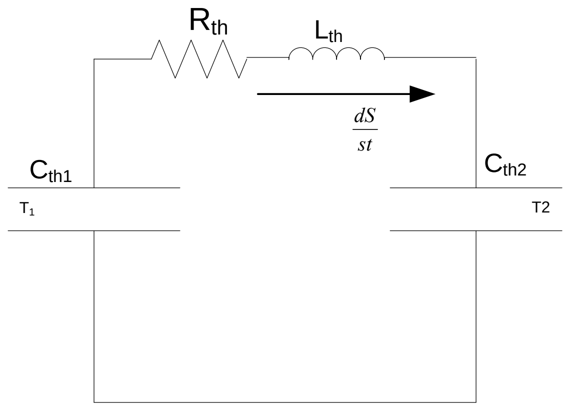

Fig. 44 Two thermal capacitors are connected through a thermal resistor

The dynamic behavioral of thermal entropy can be described using the pattern of Kirchhoff's law. For simplicity, we will assume that two thermal capacitors are identical.

$$\frac{S}{C_{th}} - \frac{(S_O - S)}{C_{th}} - R_{th}\frac{dS}{dt} - L_{th}\frac{d\ddot{S}}{\ddot{d}t} = 0, \tag{216}$$

where S_O is the initial entropy. Taking the derivative of (216), the differential equation can be written as

$$\frac{d^2 I_{th}}{dt^2} + \gamma\frac{dI_{th}}{dt} + {\omega_o}^2 I_{th}. \tag{217}$$

where $\gamma = \frac{R_{th}}{L_{th}}$ and ${\omega_o}^2 = \frac{2}{R_{th}L_{th}}$.

The solution of the second order differential equation depends on the values of L , R , and C, and therefore it has three states(cases) [86]:

$$I_{th}(t) = \frac{S_O {\omega_O}^2}{2} e^{-at} \times \begin{matrix} \frac{\sinh(\beta t)}{\beta} \\ t \\ \frac{\sin(bt)}{b} \end{matrix} \begin{cases} overdamped\ \beta = \left(\sqrt{a^2 - {\omega_0}^2} > 0\right) \\ cirtically\ damped\ a = \omega_0 \\ underdamped\ b = \left(\sqrt{{\omega_0}^2 - a^2} > 0\right) \end{cases}. \tag{218}$$

where $b = \frac{\gamma}{2}$.

Entropy as a function of time can be calculated using

$$S(t) = \int I_{th}(t)dt. \tag{219}$$

The missing energy (the energy dissipation) is independent ofR_{th}, L_{th},and the state. The missing energy can be calculated through the following equation:

$$W_{missing} \int_0^\infty I_{th}(R_{th})dt = \frac{1}{4}\frac{{S_O}^2}{C_{th}}. \tag{220}$$

This is a very important outcome, since it shows that the missing energy is independent of thermal resistor and inductors. This missing energy explains why the entropy of the system always increases. The second law of thermodynamics states that as the two masses reach an equilibrium, the entropy of the system has increased from what it was at t = 0. The entropy of the hot mass decreased, but the entropy of the cold mass increased. In other words, if the temperature of the medium is T, the entropy difference of the system can be calculated as

$$S_f - S_i = \Delta S_{system} = \frac{{S_O}^2}{C_{th}}/T. \tag{221}$$

where $S_f$is the final entropy and $S_i = 0$. Also, the dynamic behavioral of entropy can be tracked using (219).

The conventional model of heat transfer is always represented by an R-C circuit. However, the energy dynamic model suggests that the response of heat transfer can be over damped, underdamped, or critical damped, depending on β and a that are specified in (220). The only condition to represent the heat transfer using an RC circuit is when the thermal inductor is very small.

$$L_{th} < \frac{{R_{th}}^2 C_{th}}{8}. \tag{222}$$

It seems that (222) is always the case in the thermal system, and therefore the system has over-damped behavior. However, if we manipulate the domain material in order to magnify the thermal inductance, we will get under-damped behavior. This study will be a one of the future work.

6.7 Electromechanical Energy

Energy dynamics theory shows that the Co-energy concept, as defined in [87], is not necessarily to solve the energy conversion between electromechanical systems.

Fig. 45 shows the concept of co-energy in the H-B curve. The relationship between H and B are defined as

$$B = \mu_o(H + M) = \mu_o(1 + \chi_o)H = \mu H, \tag{223}$$

$$E_{co} = \int_0^{H_1} B(H)dH, \tag{224}$$

where, M is the magnetism of the material (magnetic dipole moment over unit volume), and χ is the degree of magnetization of a material in response to an applied magnetic field. Co-energy (E_{co}) is the work done by the field to bring the sample to the state of magnetization H_1 [88-90].

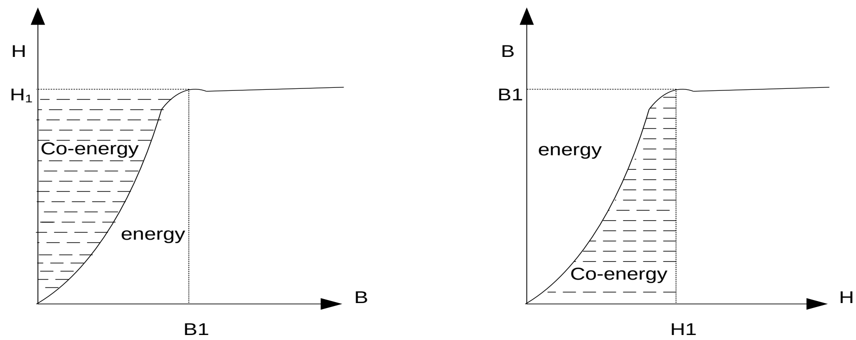

Fig. 45 Co energy in an H-B curve

In this section, we are going to introduce the co-energy method for calculating the force that is created based on the electromechanical energy conversion device as shown in Fig. 46. A comparison between the method presented in [87] and the energy dynamics model will be presented.

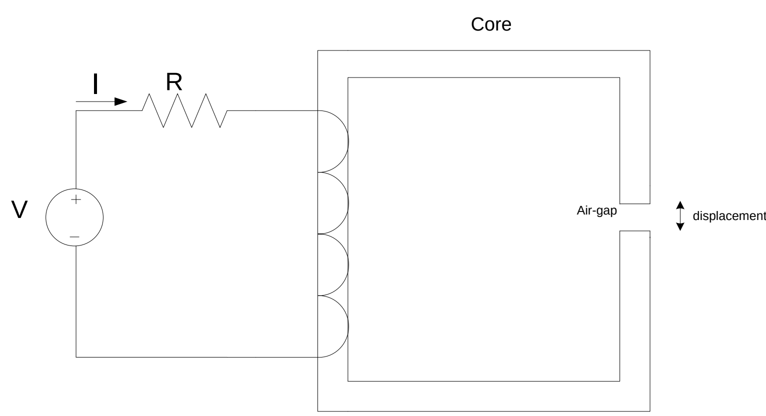

Fig. 46 An air-gapped iron core

6.7.1 Conventional Co-Energy Method

The summation of the change of magnetic energy and mechanical energy represent the change of electrical energy, as shown in Fig. 47.

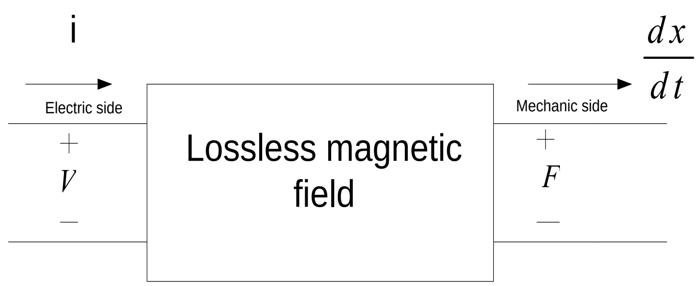

Fig. 47 Lossless magnetic system

If the system is to be conservative, energy must be a single-valued function of the independent variable (φ, x)[87, 91-93]. Mathematically,

$$V.I.dt = d(W_m) + Fdx. \tag{225}$$

where W_m is the magnetic energy, V is electric voltage, I is electric current, $F$is the force, and x is the displacement.

From Faraday's Law and Amperes' Law, (225) can be written as

$$mmf.d\varphi = d(W_m) + Fdx. \tag{226}$$

For the function F (mmf, φ), the total differential of F with respect to two independent state variables (mmf, φ) can be written as

$$d(mmf.\varphi) = d(mmf).\varphi + d\varphi.(mmf). \tag{227}$$

Substitution of (227) into (226) gives

$$dW_m = d(mmf.\varphi) - \varphi d(mmf) - F\frac{dx}{dt}. \tag{228}$$

(228) can be rewritten as

$$d(mmf.\varphi) - dW_m = \left(\varphi.d(mmf) + F\frac{dx}{dt}\right). \tag{229}$$

By definition, $d(mmf.\varphi) - dW_m$ represents the concept of co-energy, which is defined as ${W_m}'$.

$$d(W'_m) = d(mmf.\varphi) - W_m, \tag{230}$$

$$W'_m = \frac{dW'_m}{dmmf}(dmmf) + \frac{dW'_m}{dx}(dx). \tag{231}$$

Co-energy is a state function of the two independent variable (I, x). Thus, its differential equation can be expressed as

$$0 = \left(\varphi - \frac{dW'_m}{dmmf}\right)dmmf + \left(F - \frac{dW'_m}{dx}\right)dx \tag{232}$$

$$F = \left(\frac{dW'_m}{dx}\right) \tag{233}$$

From (227) and (227(230), the co-energy can be written as

$$dW'_m = \varphi d(mmf). \tag{234}$$

But $mmf = NI$; $\lambda = N\varphi = LI$, where λ is a flux linkage. Thus (229) can be written as

$$W'_m = LI\int d(I) = \frac{1}{2}L(x)I^2. \tag{235}$$

The force is then defined as

$$F = \frac{1}{2} I^2 . \frac{d}{dx} (L(x). \tag{236}$$

6.7.2 Energy Dynamics Model

Our proposed model (energy dynamics model) can easily obtain the force without using the co-energy concept.

Initially, the system shown in Fig. 48 has a magnetic voltage which is defined as

$$mmf = NI, \tag{237}$$

and has a magnetic capacitor that has a flux in it. The magnetic capacitance is defined as

$$C_{core} = \frac{\varphi_1}{mmf} = \mu \frac{A}{l}, \tag{238}$$

where l is the length, and A is the area cross section.

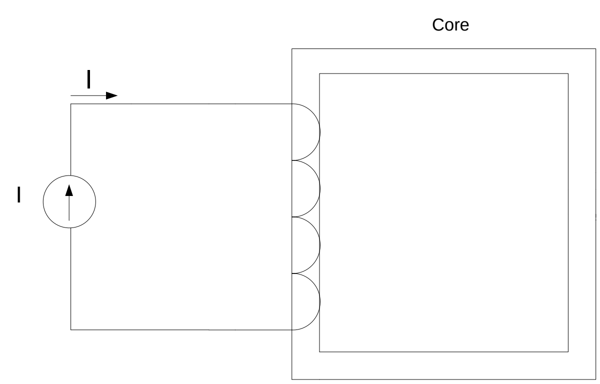

Fig. 48 The magnetic iron core with no air gap

Now, when an air gap is created, another magnetic capacitor is introduced. This capacitor represents the air gap capacitor, which is defined as

$$C_{ag} = \frac{\varphi_2}{mmf} = \mu_0 \frac{A}{l'}. \tag{239}$$

As the air gap increases, the air gap capacitor becomes dominated, as shown in Fig. 49 . Equation (239) shows that the relationship between the magnetic flux and the magnetic capacitance is proportionally linear.

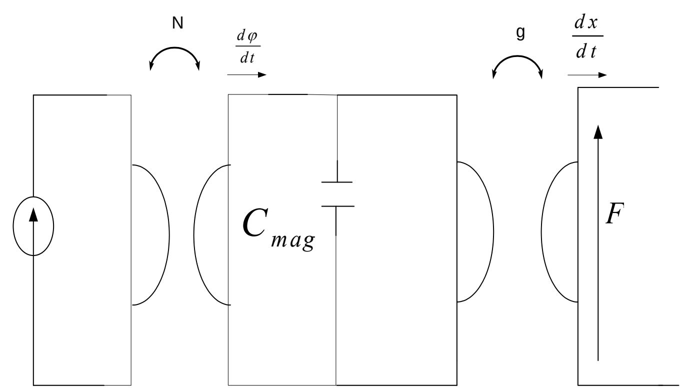

Fig. 49 The equivalent circuit of the air gapped iron core.

Since the distance between south and north increases in the air gap, a force is created and the total mechanical energy that is being stored is defined as

$$W_m = Fdx. \tag{240}$$

Conservation of energy implies that the mechanical energy and the magnetic energy should be the same. Thus,

$$\left(\frac{1}{2}mmf\right)d\varphi = Fdx. \tag{241}$$

Substitution of (239) into (241) results

$$\frac{1}{2}(mmf)^2 dC_{ag} = Fdx. \tag{242}$$

$$F = \frac{1}{2}(mmf)^2 \frac{d}{dx} C_{ag}. \tag{243}$$

Magnetic of the air gap is defined in (239), so the mechanical force can be written as

$$F = \frac{1}{2} A\mu_0 (mmf)^2 \frac{d}{dx}\left(\frac{1}{x}\right) = -0.5 A\mu_0 (mmf)^2 \ \frac{1}{x^2}. \tag{244}$$

The force can also be represented as

$$F = \frac{1}{2}\ I^2 (N)^2 \frac{d}{dx}\left(C_{mag}\right) = \ \frac{1}{2} I^2 \frac{d}{dx}\left(L_e(x)\right), \tag{245}$$

which is similar to (236).

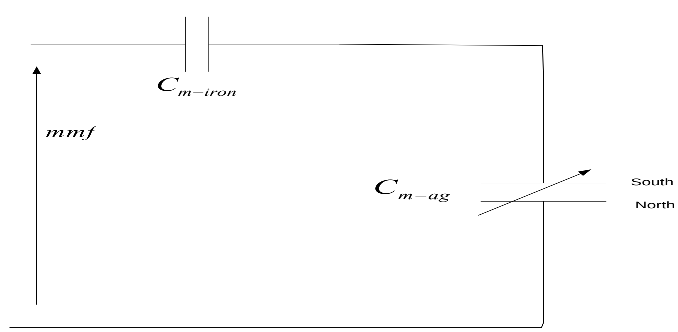

Fig. 50 The equivalent magnetic circuit for an iron core

In conclusion, we can calculate the force without using the co-energy concept.

The electric force F mutates into the velocity of the co-mechanical system that represents the rate of change of momentum. Having said that, (243) can be written as

$$u_{co} = \frac{dm}{dt} = mmf.M_{mut}\left(\frac{1}{2}\,NI\,C'\right) = mmf(g). \tag{246}$$

where g is the gyration factor and M_{mut} is the mutation factor.

6.8 Electromechanical Force

In this section, an electromechanical force will be calculated based on the energy dynamic theory. Consider a movable capacitor, as shown in Fig. 51. If the distance between two plates of the capacitor increases, the voltage across the capacitor will also increase, assuming the charges remain constant.

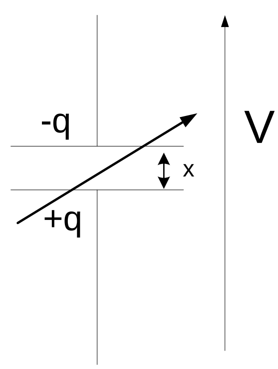

Fig. 51 A movable electric capacitor

The relationship between the distance (d) and the voltage across the capacitor can be written as

$$(\varepsilon A)V = q(x). \tag{247}$$

where ε is the electric permittivity, A is the area of each plate, x is the separation between the two plates, and V is the voltage on the capacitor.

Since the distance between two plates increases, a force is created and the total mechanical energy that is being stored is defined as

$$dW_m = Fdx. \tag{248}$$

Conservation of energy implies that the mechanical energy and the electrical energy should be the same. Thus,

$$\frac{1}{2}\frac{q^2}{C} = Fdx. \tag{249}$$

$$F = -\frac{1}{2}\, q^2\left(\frac{C'}{C^2}\right). \tag{250}$$

where C' is the first derivative of C with respect to distance, and it is defined as

$$C' = \frac{dC}{dx} - \varepsilon\,\frac{A}{x^2}. \tag{251}$$

where C is the capacitor and it defined as $C = \frac{q}{V}$ and F is the electric force.

The electric force F mutates into the velocity of the co-mechanical system that represents the rate of change of momentum. Having said that, (250) can be written as

$$u_{co} = \frac{dm}{dt} = V.M_{mut}\left(-\frac{1}{2}\,V\,C'\right) = V(g). \tag{252}$$

where g is the gyration factor and 0 M_{mut} is the mutation factor.

7 CONCLUSIONS AND FUTURE WORK

7.1 Conclusions

This research investigates the behavior of energy in different media. Energy is an abstract and pure mathematical concept, which is guided under certain laws that cannot be proven. In addition, some engineering modeling has internal inconsistencies as energy travels from one domain to another. In electrical engineering models, some studies and definitions are incomplete, such as the magnetic reluctance model, which defines a magnetic flux as a magnetic current and the reluctance as a resistance. This analogy successfully explains some phenomena and fails to explain other phenomena, and therefore we get limited answers from superficial modeling. For example, we cannot answer the following question: if the magnetic circuit is coupled to an electrical circuit through an inductor, where is the iron loss? The reactance model does not explain the losses.

The energy dynamics theory has no contradiction with the current theory. The theory addresses many of the unanswered issues and cleans all the inconsistencies that we see in the current modeling. Also, it predicts new things, such as co-gravity and hidden domains in engineering systems.

In this research, we classify the domains into two classes, namely fundamental and composite (constrain) domains, and we successfully show the transition between the fundamental domains and constrain domains. The classification of energy domains suggests that energy mutates (change its dimension) when it travels from one domain to another. That might potentially explain why there are numerical discrepancies in atomic calculations. Energy dynamic theory suggests that the mechanical mass and the electric charge are independent. In other words, an electron can travel without mass (as Higgs Boson suggests); charge can travel in space-time with no contribution of the mass whatsoever. Both mass and charge happen to be occupied in the electron.

The convectional theory suggests that the electric charge has a mass in its dimensions. However, energy dynamic theory suggests that the mechanical instrument that measures the electrical energy does some conversion and makes charge mutates to mechanical mass. Unfortunately, there is no electrical instrument that measures electrical mass.

As shown in the thesis, independent magnetic domain does not exist. The magnetic domain is always coupled with the electrical domain. Therefore, the concept of the domain and codomain for all other energy systems are presented.

We have also proposed energy dynamic conservation law that is necessary for the power conversion. This conservation law has been derived and applies to other energy systems. Also, we use this law to prove the second law of thermodynamics and the non-uniformity of the expansion of the universe.

Energy dynamic is a proportional theory. Although it has successfully explained some known observations and suggested some other observations, it has not been proven yet.

7.2 Future Work

The contributions of the work presented in this dissertation to the state of art can be summarized as follows:

1. Measure the energy variables that have been identified in a certain material using direct experiments, such as propagation.
2. Perform better finite element modeling of engineering modeling, such as magnetic for power electronics and electric motors.
3. Manipulate the domain material in order to magnify the thermal inductance since it seems that the thermal inductance is small that the medium acts virtually like an RC network.
4. Prove the existence of electric momentum (qv), that suggest a new source of energy $E = qc^2$.
5. Propose new power conversion machines.

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