The Crisis of Poynting Vector Field Power Deficiency in the Induction Motor

1. Power and energy conservation in the electromagnetic field of ordinary induction motors

Invented and developed in the last 20 years of the 19th century, induction motors have played a huge role in the development of the industrialised world. It is estimated that 85% of rotating AC machinery are induction machines and they consume around 60% of the worlds electrical power. [History Ref] They are popular for their strength, reliability and low cost and maintenance, primarily as they have no commutator and consequently do not require carbon brushes like other motors which wear down with friction and need regular replacement. This specifically reveals one of the unique features of the induction motor which is that there is no electrically conductive connection between the coils of the stator and those of the rotor. Therefore, energy and power transfer from stator to rotor conductors can only occur by the passage of power through a dielectric medium, usually air. This energy transfer suggests an ElectroMagnetic (EM) field mechanism which will be explored in this paper. Any other explanation would require action at a distance force interactions between stator and rotor conductors.

Naturally, most of the EM theory underlying induction machines is discussed in a multitude of textbooks and other publications. AC electrical power is fed into the stationary stator coil(s) assembly and this induces voltage and current in the coil(s) of a mobile rotor by the process of EM induction. The conductors in the rotor coil(s) consequently experience EM force producing mechanical torque. The EM induction is generally ascribed to Faraday's law of induction and the EM force is equal to the Lorentz force. The feature that is rarely, if ever, discussed is the power in the EM field that must flow continuously through the air gap between the stator and the rotor. Power flow in local field theory is generally ascribed to the flux of EM radiation, qualitatively either in wave or photon form or both, and quantitatively by the Poynting vector. This paper calculates the Poynting vector power flux which must flow through the air gap required by conventional local field theory to provide the measured mechanical power of an induction motor and finds it to be much greater than the continuous electrical power supplied to the machine. This apparent violation of the principle of conservation of energy leads to the open question of what mechanism or theory is actually responsible for delivering the power from the stator coils to the rotor that can remain consistent with the concept of energy conservation. A possible non-local action at a distance solution to this crisis is proposed.

2. Transfer of EM energy and momentum in field theory

2.1. The Maxwell-Lorentz-Poynting-Einstein (MLPE) Electromagnetic Field Theory

Classical (pre-1905) electromagnetic (EM) field theory is normally exclusively expressed as a combination of the four normally quoted Maxwell's equations, specifically selected and promoted by Oliver Heaviside [Hunt, Theory book], plus the Lorentz force law, Poynting's energy flux theorem and several constitutive relations and boundary conditions. This can be described as the Maxwell-Lorentz-Poynting (MLP) paradigm. The four Maxwell (Heaviside) equations are presented in both integral and differential forms in all physics textbooks that concern electromagnetism, i.e. [1], and consequently will not be presented here. It is generally conjectured that all low to medium energy laboratory measurements of electromagnetic effects including forces on macroscopic conductors, induction, radiation and energy and momentum transfer can be derived from this fundamental equation set. The underlying principles of the theory are that energy can be stored statically in the

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electric and magnetic fields but in addition electromagnetic energy / momentum fluxes are transferred through both empty space and materials. It is emphatically a local theory, implying that discrete charges and EM fields interact by co-location at specific points in space and time and at the same time discrete charges are the cause of an EM field. This creates an immediate paradox since EM field strength is inversely related to the distance from its source charge and thus co-location of a particle and its own field leads to infinite field strengths. Despite the discovery of the electron in the last years of the 19th century, and its inclusion into MLP field theory, this enigma apparently did not cause concern and was not overtly discussed. However, it did silently point to the eventual problem with infinities due to the self-energy of the electron as well as vacuum fluctuations of the EM field that would later become highly significant and awkward in the development of Quantum Field Theories (QFT) in the 1920's.

The famous four Maxwell equations propose that electric and magnetic field strengths, $\mathbf{E}$ and $\mathbf{B}$, are continuum vector manifestations (in 3-dimensional space and time) of the existence of sources, namely discrete charges ρ and their motions described as current densities $\mathbf{j}$. These equations are supplemented by constitutive relations which define the electric and magnetic field strengths within media, $\mathbf{D}$ and $\mathbf{H}$, as functions of certain physical material properties. The most pervasive of these are the permittivity and permeability which are properties of both free-space (ε_0 and μ_0 in vacuum) as well as matter (ε and μ). The supposition that the vacuum possesses material properties at first appeared intuitively incongruous and the consequence was the proposal of a luminiferous aether, but for no reason other than practical convenience, it is no longer considered to be paradoxical since empty space is also proposed to have a finite dielectric strength. A vacuum is therefore thought to conduct mechanical momentum and energy. Unfortunately, since all field detectors are made of matter, there can be no direct empirical evidence that the vacuum of free space itself actually plays any role other than providing separation and distance. To complete the description of the MLP field strengths, $\mathbf{D}$, also depends on P, the dielectric dipole moment per unit volume and $\mathbf{H}$ depends on M, the magnetic moment per unit volume. P, M, ε and μ are considered constant within linear isotropic homogeneous media, but in many real materials become more complex and variable.

Another pillar of the currently accepted electromagnetic paradigm is the Lorentz force law, describing the force on a charged particle as a function of its charge, Q, the co-located values of $\mathbf{E}$ and $\mathbf{B}$ and the velocity, $\mathbf{v}$, of the charge relative to the inertial frame in which the force measuring equipment is at rest. It became apparent within a few decades of its proposal that if the MLP paradigm could be correct then the arbitrary choice of detector reference frame must alter both the electric and magnetic field strength vectors in order to develop the force which had to be the same (invariant) for a detector which could be viewed from any inertial (non-accelerating) frame. Therefore, the field strengths, attributed to Maxwell's and Lorentz's equations on their own, did not conform to the principle of relativity. Feynmann [4] conjectured that this property of the magnetic field being able to vary, or even become zero, based on the arbitrary choice of motion of the detector implies that the concept of "a real field" was not meaningful. In the early 20th century, this awkwardness of interpretation was considered to be not so important for experiments with stationary or slowly moving detection instruments with respect to a laboratory but was problematic to the burgeoning study of charged particle beams and high energy physics which required a more precise theory involving both source and detector particles either accelerating and / or moving near the speed of light.

Einstein famously recovered the Maxwell-Lorentz-Poynting (MLP) paradigm in 1905 by combining it with both the mathematical Lorentz transformations, proposed independently by Lorentz and Fitzgerald in the 1890's to resolve earlier problems in optics, and his still to this date empirically unfounded assumption of the constancy of the one-way speed of light with respect to all

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inertial sources and detectors. [5] is just one example of a text giving a complete derivation of the special relativistic transformation of the fields which allow the Maxwell-Lorentz-Poynting-Einstein (MLPE) field theory equations to provide field and force solutions which allow the principle of relativity to hold for all practical macroscopic field and force detectors in any arbitrary inertial frame.

2.2. Field Energy in the Maxwell-Lorentz-Poynting (MLP) paradigm

Electrostatic field energy is the stored energy in the field due to a distribution of static charges and in analogy magnetostatic field energy is due to an instantaneous distribution of current densities. $\mathbf{E}$ and $\mathbf{B}$ may be changing in time, but the accepted description of the scalar stored field energy, U, in a volume, V, at all times is

$$U = \int_V \left(\frac{\varepsilon_0}{2}\mathbf{E}\cdot\mathbf{E} + \frac{\varepsilon_0 c^2}{2}\mathbf{B}\cdot\mathbf{B}\right) \mathrm{d}V \text{ (J)}. \tag{1}$$

It is important to note that while the integrand of Eq (1) dimensionally represents a volume density, it is important to note that in keeping with the local nature of MLP field theory, it is not possible to describe the stored energy density at a given point in space and time as it is a representation of the distribution and motions of charges which are not necessarily in that location.

The equations of the MLP paradigm, prior to Einstein's enhancements, had been used to derive further electromagnetic field phenomena. The most famous of these is the development of the two wave equations in vacuum in the case of no sources (charges). Using the values of the permittivity and permeability of free space (ε_0 and μ_0) , algebraic manipulation of the four Maxwell equations and application of a standard vector identity yields:

$$\nabla^2\mathbf{E} - \varepsilon_0\mu_0\frac{\partial^2\mathbf{E}}{\partial t^2} = 0 \tag{2}$$

and

$$\nabla^2\mathbf{B} - \varepsilon_0\mu_0\frac{\partial^2\mathbf{B}}{\partial t^2} = 0\,. \tag{3}$$

Eqs (2&3) can be seen to be wave equations in 3-dimensional space and in combination are generally taken to represent electromagnetic waves travelling through space at velocity of $1/\sqrt{\varepsilon_0\mu_0}$. In vacuo this velocity is the constant, c, (2.998x10^8 m/s) now referred to as the speed of light. Within material media or near significant masses, the velocity of wave transmission is always lower than this value.

The constant, c, was first discussed by Weber and measured by him and Kohlrausch in the early 1850's as the ratio of electromagnetic to electrostatic units of charge in the Newtonian, non-local Instantaneous-Action-At-A-Distance (IAAAD) force laws of Ampére, Weber and Coulomb [6]. In 1857, Kirchoff highlighted that this measured constant was a ratio of time to distance, but in units of velocity it was roughly equal to the, deduced one-way interplanetary, and laboratory measured, two-way terrestrial speed of light. Kirchoff demonstrated that it also represented the speed at which his new circuit theory predicted the propagation of electric disturbance along a perfectly conducting wire [7]. Arguably Maxwell's greatest theoretical achievement was the equating of Weber's action at a distance ratio of differing charge quantities with the velocity of electromagnetic wave transmission in his novel local field theory of light in 1864 [8]. To draw attention to the nature of this surprising connection between non-local and local

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theories of electromagnetism, even Maxwell ironically stated that "The only use of light in the experiment [measurement of c by Weber & Kohlrausch[6]] was to see the instruments"[7].

Maxwellian wave theory remains at least part of the modern model of electromagnetic (EM) radiation including light. There is of course also the quantum mechanical conception of EM radiation, namely photons, and the two models are considered to slightly uncomfortably coexist, although famously never revealing both aspects to the same detector at any one time. Generally, photons are routinely discussed in situations where field strengths are oscillating at frequencies greater than 10 MHz. This lower frequency limit represents the longest wavelength (30m) radiation detectable by radio astronomy. However there has been effective long distance radio communication transmission through the earth and sea in the ELF band (Extra Low Frequency) at frequencies down to 30 Hz. At this frequency, the wavelength is 10^7 m. It consequently becomes more difficult to conceive of the photon at this end of the EM radiation spectrum, but nevertheless there is no lower cut off frequency expressed in Eqs (2&3) nor in the theory of the photon. Therefore, in the MLPE paradigm, energy can theoretically propagate through both matter or a vacuum at frequencies down to but not including 0 Hz with infinite wavelengths.

2.3. Poynting's Theorem

The local interaction principle lying at the heart of the MLPE paradigm in which energy can only be transmitted at a finite velocity (less than or equal to c) requires a mechanism to describe energy flux specifically to preserve the law of conservation of energy at all times. In other words, when a source of radiation loses energy, the field must contain and transmit this energy before it eventually arrives at a sink. Detection of this transmitted flux through a closed surface is either in the form of an electrical power (Energy per unit time) delivered to a system of charges per unit volume ($\mathbf{E}\cdot\mathbf{j}$) or a mathematically related mechanical momentum as in the phenomenon called radiation pressure (Impulse per unit time per unit area). Unless the target is a superconductor, the ultimate form of the electrical power is Joule heat.

In 1884, Poynting proposed a theorem based on the balance that the power (energy per unit time) lost by the fields in vacuum must equal the power gained by charged particles in a volume plus the power flow out of the volume expressed as

$$\frac{\mathrm{d}U}{\mathrm{d}t} = \int_V \mathbf{E}\cdot\mathbf{j}\,\mathrm{d}V = -\frac{\partial}{\partial t}\int_V \frac{1}{2}(\varepsilon_0\mathbf{E}\cdot\mathbf{E} + \varepsilon_0 \mathrm{c}^2\mathbf{B}\cdot\mathbf{B})dV - \oint_S \varepsilon_0\mathrm{c}^2(\mathbf{E}\times\mathbf{B})\cdot\mathrm{d}A\ (\mathrm{W}). \qquad (4)$$

The integrand in the 2^{nd} integral on the RHS of Eq (4) is referred to as the Poynting vector. Heaviside, Feynmann and others have all described that the Poynting vector can be augmented by the addition of other field vectors as long as their divergence is zero within the enclosed surface, S, surrounding the volume, V[9]. None of these extra vector terms have ever been discovered experimentally and thus the simplest expression for the energy flux density in units of power per unit area and generally referred to as the unique Poynting vector, $\mathbf{S}$, in S.I units is

$$\mathbf{S} = \varepsilon_0\mathrm{c}^2(\mathbf{E}\times\mathbf{B}) = (\mathbf{E}\times\mathbf{H})\ (\mathrm{W/m^2})\,. \qquad (5)$$

It is important to recognize that the vector, $\mathbf{S}$, can only be interpreted within the context in which it was derived, namely as the integrated energy flux into or out of a closed surface. Many authors have correctly pointed out the paradoxes that can come about if this condition is ignored. [10] For instance, a static charged particle adjacent to a static bar magnet will produce static $\mathbf{E}$ and $\mathbf{B}$ field strengths, but the existence of a non-zero Poynting vector implies a continuous flow of energy through empty space although no measurable charges are in motion. It is discovered in this case that the theoretical Poynting energy flow is circulating and whatever flows into any volume (that does not contain one or both of the sources) also flows out. Feynmann, Vol 2, 27-5 [11] went so far as to describe this situation as a demonstration that the Poynting vector theory is "obviously nuts". However, he does not discourage further application of it with due care. Consequently, it is now taken that the Poynting vector theory only describes energy transfer from a source to a sink only if the integral through a closed surface is non-zero, implying that there is a net energy source or sink within the enclosed volume.

The Poynting vector theory was quickly accepted as it was particularly successful in being consistent with the transport of energy in DC and AC circuits. Closed surfaces could readily be imagined enclosing sections of a conducting circuit. If the enclosed components are net emf producing such as discharging batteries or capacitors, then there is a net Poynting energy flux out of the region and if the component is a net resistive component, then there is a net energy flux into the enclosing surface. Further the incoming Poynting energy flux can be **completely equated** to the easily measured Joule heat loss (for non-superconductors). This however does leave open the question of where the extra energy required to cause conductor motion comes from in the case of a motor for instance. MLPE field theory when applied to electro-mechanical circuits provides no explanation for the source of this motive energy.

2.4. Electromagnetic Momentum Flux

According to [12 Loudon&Baxter] the first mention of a possible connection between light and a flux of linear momentum appears to be Kepler's conjecture that light streaming from the sun influenced the direction of the tail of a comet. In the intervening 400 years, the subject has been continuously discussed and researched. Various historians [13] have compiled tales of the tribulations of many attempts to measure what is now called "radiation pressure". Unfortunately, it has proven extremely difficult to distinguish this force from that which occurs simultaneously as a result of photothermal effects that increase the gas temperature and pressure at a detector blade exposed to a light source. Attempts to resolve this confusion have involved measurements in low, high and atmospheric pressures, light and heavy detector vanes, mechanically driven oscillating sensors, modulated lasers and extremely sensitive detectors and yet the result can still not be fully confirmed although at many times, for over 100 years, measurements have been very close to that predicted by field theory [14] Partanen et al, Nature 2020], namely

$$F = \frac{2P}{\mathrm{c}} = \frac{\mathrm{d}p}{\mathrm{d}t}\ (\mathrm{N})\,, \qquad (6)$$

where F is the force of radiation pressure on a detector vane and P is the optical power entrained on it when the radiation is fully reflected. p is the electromagnetic field momentum associated with the incident radiation. This force is currently thought to be caused by the momentum exchange between the incoming photons, with total momentum flux (P/c), and the target and is doubled by their reflection. Naturally using the conservation of momentum, the model assumes that if the photons are fully absorbed by the target, then the force will be half that predicted by Eq (6).

Since the 17th century, the two dominant overarching conjectures concerning the nature of light remain the wave theories originally championed by Descartes and Huygens and the corpuscular

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concepts first promoted by Newton which stemmed from ancient philosophies from Empodecles and many others. Ironically, evidence of radiation pressure was initially seen to support the corpuscular model and disprove the wave theory. However, this all changed with Maxwell's proposal of travelling electromagnetic waves in a mechanical aether as a new interpretation of light. It then seemed natural to propose in analogy with acoustic waves in matter that a mechanical luminiferous aether could support energy in the form of electromagnetic waves and could therefore transfer momentum and force to a target containing a plane perpendicular to the direction of the incident light. Maxwell [15] 3rd ed, Vol 2, Art 793] appears to be the first to use this concept to derive the force per unit area acting on the earth due to sunlight, but correctly recognized that this was too small to easily measure. He nevertheless expressed hope that future experiments could reveal this pressure with electric light sources and detector vanes in vacuum. Although he did not spell out the relation in an equation in the Treatise, Maxwell clearly identified that the numerical factor relating the Energy flux density of the incident radiation and the pressure acting on a surface was the velocity of the radiation itself which in his theory was always the constant, c, and therefore independent of frequency.

In the first decade of the 20th century, several physicists including Poynting and Lorentz, addressed what M. Abraham would later call "electromagnetic momentum". Lorentz [16] chap1, sec 24] defined it as the vector quantity, $\mathbf{G}$, contained in a volume, V, and related it to the Poynting vector by

$$\mathbf{G} = \frac{1}{c^2}\int_V \mathbf{S}\,\mathrm{d}V = \varepsilon_0\mu_0 \int_V \mathbf{S}\,dV \ \ (\mathrm{kg\ \ m/s}). \tag{7}$$

Further, when specifically considering radiation pressure due to a plane light wave, it was deduced that the time average rate of change of momentum per unit area, which is the momentum flux density (electromagnetic momentum passing through unit area per unit time), is related to the average magnitude of the Poynting energy flux by

$$\frac{\langle\dot{\mathbf{G}}\rangle}{dA} = \frac{1}{c}\,|\bar{\mathbf{S}}|\left(\frac{\mathrm{kg\ \ m/s}}{\mathrm{s\ m^2}}\right)\mathrm{or}\left(\frac{\mathrm{N}}{\mathrm{m^2}}\right). \tag{8}$$

Eq (8) reveals that the average magnitude of the Poynting vector passing through an area, dA, divided by, c, the speed of light, is a mechanical pressure.

The modern requirement for the existence of EM field momentum is a fundamentally necessary consequence of the present reliance on the Lorentz force law which can predict unbalanced (non-Newtonian) forces acting on two interacting moving charges in isolation from all other sources. In other words, the Lorentz law predicts that the total mechanical momentum of the pair can self-increase (see FigureXX). In order to preserve the principle of the conservation of momentum, an equal and opposite amount of electromagnetic momentum must be created and radiated into free space, to ensure that two isolated interacting charges cannot increase the total momentum of the universe.

2.5. Tensors in Field Theory

Apart from Einstein's proposals described in Sec. 2.XX to facilitate the retention of Maxwellian field theory for all inertially moving observers and particles, one of his other major contributions to theoretical physics was as a proponent of the introduction of Tensors of the 2nd rank into physics. 0^{th} and 1^{st} rank tensors were already known in the form of scalars and vectors respectively. One of the most utilised tensors in physics is the 2^{nd} rank Maxwell stress tensor, $\overleftrightarrow{\mathbf{T}}$, which was not developed by Maxwell, but named in his honour nevertheless. It is derived from the famous 4 Maxwell equations and the Lorentz force and describes the force per unit area (stress) acting on an imaginary surface. It is often written as a symmetric (3×3) matrix, where each element, $T_{ij} = T_{ji}$, is the force per unit area in the ith direction acting on an element of the surface, dA, whose unit vector normal, $\hat{n}$, is in the jth direction. Therefore the three diagonal elements T_{xx}, T_{yy}, T_{zz} can be identified as pressure on the surface and the other 6 can represent shear forces. If the closed surface happens to be the outer surface of a 3 dimensional object, then the Maxwell stress tensor describes the net electromagnetic force on it and in this regard, it can be very efficient in EM computer modelling since it is then not required to consider the Lorentz force acting on each internal volume element within the surface.

The Maxwell stress tensor on the outer surface completely surrounding a conductor is by definition related to the net force on the object, $\mathbf{F}_{total}$, or its rate of change of mechanical linear momentum by

$$\mathbf{F}_{total} = \frac{d\mathbf{p}_{mech}}{dt} = \oint_S \overleftrightarrow{\mathbf{T}} \cdot \hat{n}\, dA - \varepsilon_0 \mu_0 \int_V \frac{\partial \mathbf{S}}{\partial t}\, dV \ \ (\mathrm{N}). \tag{9}$$

Comparison of (7) and (9) reveals that the 2^{nd} term on the RHS of (9) is the rate of change of the electromagnetic momentum in the enclosed volume and therefore represents the rate at which net electromagnetic momentum, $\mathbf{p}_{em}$, in the volume is being converted to mechanical momentum, $\mathbf{p}_{mech}$. Eqs (5)(7)&(9) all reveal that the electromagnetic force, momentum and energy are different ways of expressing the same phenomenon. This is now most succinctly expressed as a quantity generally referred to as the electromagnetic stress-energy tensor, $T^{\mu\nu}$ (Electromagnetic) and generally interpreted as the flux density of the electromagnetic momentum four-vector. It is based on Minkowski / Cartesian 4-dimensional space-time coordinates of special relativity in which the time component is multiplied by c, the speed of light, to give it the dimension of length. $x^{\mu} = (ct, x, y, z)$. It is usually expressed in contravariant form as the 2^{nd} order tensor,

$$T^{\mu\nu}(\text{Electromagnetic}) = \begin{pmatrix} u & S_x/c & S_y/c & S_z/c \\ cg_x & -T_{xx} & -T_{xy} & -T_{xz} \\ cg_y & -T_{yx} & -T_{yy} & -T_{yz} \\ cg_z & -T_{zx} & -T_{zy} & -T_{zz} \end{pmatrix} = \begin{pmatrix} u & \left(\frac{\mathbf{S}}{c} = c\mathbf{g}\right) \\ \left(\frac{\mathbf{S}}{c} = c\mathbf{g}\right) & \overleftrightarrow{\mathbf{T}} \end{pmatrix}. \tag{10}$$

In the condensed matrix on the RHS of (10), the upper and lower diagonal elements are the stored EM field energy, u, and the Maxwell stress tensor respectively. The two identical off-diagonal elements are often described either as the field momentum density or energy flux and dimensionally represent the electromagnetic momentum passing through unit area per unit time or a pressure in agreement with Eq (8).

The electromagnetic stress-energy tensor is so ingrained in modern physics that it is a contributory component of the total stress-energy tensor which also includes the material stress-energy tensor describing the energy (mass) and momentum of matter. The combination of the two tensors yields the total stress-energy tensor, $T^{\mu\nu}$, which is the source term at the heart of Einstein's theory of gravitation, General Relativity. His famous equation, usually written in covariant form but for comparison with Eq (10) is here expressed in equivalent contravariant form,

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$$R^{\mu\nu} - \frac{1}{2} R g^{\mu\nu} + \Lambda g^{\mu\nu} = \frac{8\pi G}{c^4} T^{\mu\nu} , \tag{11}$$

where $R^{\mu\nu}$ and R are the Ricci tensor and scalar respectively, $g^{\mu\nu}$ is the spacetime metric, Λ is the cosmological constant and G is Newton's gravitational constant [17]. This reveals that the currently accepted physics paradigm places the transfer of electromagnetic energy and momentum via the Electric and Magnetic fields as expressed in the Poynting vector as a fundamental property of the universe.

3. Calculation of the Field Energy Deficiency in Induction Motors

A schematic depiction of a generic induction motor is shown in Figure 2?. It consists of two components, namely a stator fixed to the earth and a rotor which is free to rotate. The rotor has mechanical connection to the earth via its axle and sets of low friction bearings, but has no electrically conductive connection to anything external. It consists of one or a set of independent conductive coils as well as ferrite to improve the mutual inductance between rotor and stator coils. The stator is mechanically fixed to the earth and also comprises of several sets of conductive coils and ferrite. Oscillatory current is fed into different stator coils as a function of time. The rate of change of the current in the stator coils as well as the relative motion between the rotor and stator coils induces voltage and current in the rotor coils. The relative motion also induces back-emf voltages on the stator coils. The net consequence of current flowing in both sets of coils is a varying but fairly constant force acting to produce torque on the rotor assembly which can then be converted to mechanical energy.

Current is fed into several sets of coils in the stator, usually with a three-phase power supply in a cyclic manner, which fixes the rotational no-load synchronous speed of the motor, as a function of the number of sets of independent stator coils and supply frequency. Under load, the rotor rotates usually at a speed, ω , between 95-97% of the synchronous. The difference between the two angular speeds is called the "slip" and is a function of the mechanical load, bearing friction and rotor coil resistance. The higher the stator currents, the higher is the mechanical output torque of the motor, T. The mechanical power output, P_{mech} , is given by

$$P_{mech} = \omega T \text{ (W)} . \tag{12}$$

The ratio of mechanical power to the electrical input power yields the motor efficiency which is often higher than 95% and this type of device is consequently technologically useful and well parameterised.

Although it is never discussed in the literature with regard to induction motors, for completeness the local MLPE field theory must contain a mechanism that transports the energy to drive the rotor current in addition to one that transports the momentum and energy flux that travels from the stator through the air gap and is eventually delivered and consumed by the rotor and converted to mechanical energy and torque. This gap between stator and rotor usually consists of air, but could also be vacuum or in fact any insulating substance which allows the rotor to slide past it. Air or vacuum can be considered equivalent as they both have roughly the same permeability, μ_0. For the motor to receive continuous force to work against a load, net electromagnetic momentum must continuously cross the closed surface at the outer surface of a coil of the rotor on which the Lorentz force must be impressed. As described throughout Sec. 2, the only mechanism in MLPE field

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theory, and all of the currently accepted body of physics, that can transfer momentum via locally acting fields is the Poynting vector. In Sec. 2.4, it is shown to be consistent with radiation pressure, however it must also be able to predict all electromechanical phenomena including the induction motor.

Since a real induction motor is likely to have more than one rotor coil, the surface discussed here is the set of one or more closed surfaces describing the outer surfaces of the entire set of rotor coils. At every point on this surface, the Poynting vector flux, **S**, defined by Eq.(5) , will have a zero or non-zero component perpendicular to the surface. This inward net power flow integrated over the surface will therefore also be a lower bound to the total power flowing in the field as there may also be a tangential component to **S**. If the motor was running at full synchronous speed with unrealistic zero mechanical load or bearing friction, the Poynting flux would be purely tangential to the surface defined by the coils which themselves would be consequently passing zero current. However, at all times when the motor is mechanically loaded and/or incurring bearing friction, there must be a continuous net inward flow of field power which is being consumed and converted to heat and mechanical momentum.

In a motor under mechanical load, the net field energy per second (power) that does penetrate the total rotor coil surface, P_{field} , can therefore be defined by

$$P_{field} = \oiint_{rotor} (\mathbf{S} \cdot d\mathbf{n})\, dA \quad (\mathrm{W}) \tag{13}$$

The interpretations of both Eqs.(8 & 10) reveal that the Poynting flux when divided by the speed of light is the corresponding momentum flux density or a pressure. Therefore, the average pressure caused by momentum flow through a surface element dA due to the normal component of the Poynting vector at that location is

$$\frac{\langle dF_{EM} \rangle}{dA} = \frac{\langle (\mathbf{S} \cdot d\mathbf{n})_{dA} \rangle}{c} \left(\frac{\mathrm{N}}{\mathrm{m}^2}\right). \tag{14}$$

This average pressure integrated over the entire rotor surface is ultimately measured as average continuous motor output torque, T_{meas} . A low estimate of motor torque due to this momentum transfer can assume that the force is delivered purely tangentially to the rotor radial vector and at the largest possible distance from the axle centre, namely, the rotor radius, r . Consequently,

$$T_{meas} \leq \oiint_{rotor} r \frac{\langle dF_{EM} \rangle}{dA}\, dA = \oiint_{rotor} r \frac{\langle (\mathbf{S} \cdot d\mathbf{n}) \rangle}{c}\, dA \; (\mathrm{Nm}). \tag{15}$$

In order to calculate the field power that must continuously pass through the rotor surface in order to sustain the electromagnetic pressure on the rotor and create the measured output torque, Eqs.(13) and (15) can be combined yielding

$$\frac{c\, T_{meas}}{r} \leq \oiint_{rotor} \langle (\mathbf{S} \cdot d\mathbf{n})\, dA \rangle = \langle P_{field} \rangle \; (\mathrm{W}). \tag{16}$$

The maximum torque, T_{meas} , of a quoted industrial induction motor can then be inserted into Eq.(16) along with the maximum radius of the rotor, r , and the speed of light, c . This reveals a minimum estimate of the net continuous power flowing from stator to rotor in the EM field, P_{field} ,

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irrespective of any EM energy that might be stored and circulating within the air gap. It is also a low estimate because it does not contain any of the power required to drive the current in the rotor coils which is continuously converted to Joule heat. Comparison of the minimum continuous EM field power requirement with the quoted maximum input electrical power of the motor reveals that the electrical supply to any induction motor is insufficient to create the required field power by the principle of conservation of energy. This inadequacy of the MELP field theory is revealed for two typical commercially available induction motors described in Table 1 and the ratio of required field power to available electrical input power can be as large as 7 orders of magnitude and appears to be true for all induction motors. It highlights that MELP theory has rarely, if ever before, been experimentally put to the test on electromechanical machinery with regard to a quantitative prediction of the required power flow in an EM field in a region of free space (free of detecting equipment), and is now shown to be inadequate by the principle of energy conservation. The fact that this discrepancy exists, never mind that it is so large, casts doubt on the entire MLPE paradigm.

ABB Induction Motors - (400V, 50Hz, 3Phase) - All measurements at nominal load								
Model	Poles	speed (rpm)	P (Elec Input) (kW)	Torque (Nm)	Motor radius > r (rotor) (m)	P (Mech) (Torque x speed) (kW)	P (field) requirement from Eq.(16) (kW)	P (field) / P (Elec Input)
M2VA 56A	2	2820	1.53E-01	0.31	0.055	9.15E-02	1.69E+06	1.10E+07
M2CA 400LKA	8	744	3.27E+02	4043	0.403	3.15E+02	3.01E+09	9.19E+06

Table 1: ABB catalogue parameters and deduced field power requirements for 2 standard induction motors, revealing the MLPE field power deficiency

4. Conclusions

The MLPE paradigm has been very successful and fully embraced since Einstein's final addition of the Lorentz transformation to the Maxwell-Heaviside field equations. It has yielded the conceptions that have led to the modern description of the EM spectrum and the travelling self-propagating EM wave, leading to the development of efficient transmission and detection antennae and wave guides. It is at least consistent with the difficult measurements of pressure on a surface which is thought to be under the influence of EM radiation. Also, it has helped to identify electric and magnetic properties of materials, however at the expense of having to apply some of these to a pure vacuum to maintain the illusion of a medium which controls the speed of EM transmission through it. The paradigm encompasses the Lorentz force as the sole mechanism by which EM fields act on moving charged particles. This force law has been successfully used to design a vast array of electromechanical machinery and physical experiments from motors to particle accelerators. In almost all cases, the predicted force is perpendicular to the direction of movement of the charged particle receiving the force and in quantitative agreement with the Lorentz force, leading to the present conviction that it represents the universal EM force law. For these benefits, the MLPE paradigm including the theories of Special and General Relativity have become the accepted continuum local field theory paradigm.

There are however two reasons with which to suspect that the local continuum MLPE theory is not a fundamentally valid paradigm. These are (a) the success of the vast body of quantum mechanics theory and calculations which are inherently non-continuum and non-local and (b) the less well-known reports of EM forces with components in the direction of charge motion which cannot be the result of the Lorentz force which by definition, can only act perpendicular to charge motion.

The success of quantum mechanics in particle accelerator and detector design and very highly accurate comparison of theoretical and experimental results, has made it, so far, the most

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highly praised aspect of the modern physics canon. It is, however, well recognized that it cannot yet be brought into agreement with the theory of General Relativity, thus leaving an incongruence between the theories of the very small and the very large. As shown in Sec. 2.5, the Poynting vector lies at the heart of the theory of General Relativity and this paper has revealed a huge inadequacy in the Poynting vector mechanism of EM power transfer. It therefore seems inevitable that of the two currently inconsistent paradigms, it is General Relativity that is most likely to be found to be incorrect and thus a new theory of gravitation will ultimately be required. When a new theory of gravitation is ultimately found, it will hopefully have a non-continuum non-local basis at its heart thus removing the present crisis in physics [Bruno Mansoulie].

The first law of EM force was proposed by Ampere in 1822 and was a Newtonian Instantaneous Action At Distance (IAAAD) force law. Without the constraint of the vector cross product inherent in the Lorentz force law, Ampere's law was capable of predicting EM force on a current element in any direction including a longitudinal component in the direction of charge motion (electric current). For more than 200 years, there has been a continuous debate concerning whether there was an experimental demonstration of this longitudinal component which would violate the validity of the Lorentz force.

TBC…

[XX] Induction motor history: DOI 10.1109/MELE.2023.326488
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[2] Feynmann QED p.128
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[11] Feynmann, Vol 2, 27-5
[12] Loudon and Baxter
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In the early years of Quantum Field Theory (QFT), some artificial mathematical techniques, (a "shell game", "hocus-pocus", "dippy process" [2] or "tricks" [3] according to Feynmann) usually referred to as renormalisation, were applied in which the otherwise continuum EM field very close to a charge is artificially excluded from calculation without any justification other than it allows quantum mechanics calculations to become possible. This license to apply quantum mechanical without deep understanding became common place as typified by the phrase, often and perhaps incorrectly ascribed to Feynmann; "Shut up and calculate!", most typically used to irrationally defuse the paradoxes thrown up by the Copenhagen interpretation.

The embarrassment of ignoring certain quantum mechanics coefficients just to achieve the expected results that agreed well with experiments was nevertheless considered unacceptable until the publications by Wilson [XX] concerning renormalization groups and what is now call “Effective Field Theory” (EFT). This work exploited the large gaps in length scale between

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