

## Design Techniques for New Engineers

### Misleading Terminology

by Dennis L Feucht

Power electronics (including motion control) has an unusually high occurrence of misleading terminology. When taken at face value, misnomers result in confusion for neophytes and conceptual abstruseness in the literature of the field. Misleading language is slowly being replaced but plenty of it is still around.

### Scientific Language

Language and its components – words – matter. Words themselves don't mean anything, but *we* mean something by them when we use them. To *define* a word is to “show limits,” to limit the range of meanings it can signify. When the range of meanings is wide, such words label *ideas*. Narrower defined meanings are *concepts* instead. If a car were defined as a vehicle with four wheels and an engine, then some trucks and tractors would be included in the definition. Such a definition is conceptually too broad to be useful in distinguishing between such vehicles.

In the tradition of science and engineering, meanings labeled by key words are made sufficiently narrow in their range of meaning to avoid ambiguity. Key concepts have a one-to-one correspondence with the words that label them. This standard use of language in science and technology is not always maintained, and confusion can result.

### Dc, Ac, and Dynamic

The well-established expressions *dc* and *ac* in electrical and electronics literature are archaic but very much with us. The problem with them is that each labels more than one concept, causing confusion at times. *Dc* can mean constant with time or *static*, or it can mean unipolar: of one polarity (either + or -). The meanings are not the same. *Ac* can mean changing with time or bipolar. Therefore, it is better that these old terms be phased out in preference for saying more precisely what we mean. Static does not mean unipolar and varying or changing does not mean bipolar.

A related confusion can occur over the word *dynamic*, which sometimes means varying or changing, while at other times it more correctly means the involvement of complex variables and reactance. It is not uncommon to read transistor model parameter,  $r_e \approx 26 \text{ mV}/|I_E|$  as “dynamic emitter resistance” as opposed to static emitter resistance. There is a difference; static emitter resistance is  $V_{BE}/I_E$  whereas  $r_e = dv_{BE}/di_E = v_{be}/i_e$ . In this conventional electronics notation, symbols for quantities of the form  $X_Y$  (all upper-case letters) are *static* quantities;  $x_y$  (all lower-case) are *small-signal* or *incremental* quantities; and  $x_Y$  are *large-signal* or *total-variable* (static and incremental combined) quantities, which are the complete functions. *Dynamic* sometimes is used to mean *incremental*, and this can cause confusion. Be aware of the two meanings of *dynamic*. Happily, *static* does not seem to be ambiguous.

### Electrical and Magnetic Quantities

Magnetic field intensity,  $\mathbf{H}$ , in SI units of A/m, is alternatively referred to as magnetic field strength. Having two expressions for the same quantity, while not necessary, is not confusing. The two expressions accurately name the quantity. A related quantity, magnetic field density,  $\mathbf{B}$ , in units of V-s/m<sup>2</sup>, is sometimes called *induction*. Two labels for a single concept, while not parsimonious, are not confusing.

In introductory physics textbooks, it is not uncommon to encounter the expressions *EMF* and *MMF*, abbreviations for “electromotive force” and “magnetomotive force.” respectively. These quantities are more properly named the *electric* and *magnetic potential*, respectively. The electric potential in most cases found in electronic circuits is equal to *voltage*, due to the ohmic drop of current across an impedance. *Voltage* is the more general quantity and includes not only electric potential (which appears as differences in circuits) caused by ohmic drop and magnetically-induced voltage (as in a transformer), but also due to the movement of closed conductive paths in a magnetic field (as in motors), where closed wire loops “cut through” magnetic flux, described by the familiar flux-cutting equation:

$$v = B \cdot l \cdot u$$

where,  $u$  is speed.

These three phenomena produce voltage, and we commonly use the word “voltage” instead of “potential difference” because it includes all the causes of the quantity.

However, voltage is not force. The quantities are distinct and require distinct labels. The unit of voltage is the *volt* (V), which is not convertible to any unit of force, such as the SI unit of the newton (N). To refer to voltage as “force” is to mislabel the kind of quantity that voltage is. Historically, discovery of forces involving electric and magnetic fields led to a confusion of the familiar quantity of force from Newtonian mechanics with hitherto unknown electrical quantities. The confusion is understandable; experimenters try to relate new phenomena to known physical quantities. Yet voltage, and its magnetic counterpart, MMF, are not forces.

MMF has units of amperes, A, not newtons. The expression, MMF, used without referring to it as an abbreviation of “magnetomotive force” is more resilient than EMF and is still found in motor textbooks. Its proper name is “scalar magnetic potential” with symbol  $\phi^*$ . (See, for instance, *Basic Electromagnetic Theory*, by Paris and Hurd, McGraw-Hill, 1969, p 229.) Personally, I prefer to symbolize magnetic potential (the magnetic Ohm’s Law equivalent of voltage) as  $N \cdot i$ , or “ampere-turns” instead of MMF or  $\phi^*$  when working out motor and transformer theory. (The *turn*, like the *radian* is not a unit as such, but a scaling factor which is often mixed in with units.)  $N \cdot i$  is the terminal current referred to the field reference-frame, where  $N$  turns effectively make the current appear  $N$  times as great. Similarly, induced voltage, referred to the field side of the circuit is  $v/N$ , but lacks a name.

## Motor Language

There are three basic means of producing torque with magnetic fields. For one of them, a stationary field orientation at right angles to the stator field is maintained by switching current through commutating brushes to the rotor winding that produces the oriented field. Motors based on this principle are called “dc motors” because a static voltage can be applied to their terminals.

The permanent-magnet synchronous (PMS) motor (the second means) requires varying, bipolar (*ac* in both meanings) excitation of its windings, so that the rotating magnets’ field orientation is at right angles to the rotating field produced by the stator windings. The alternating magnetic polarity (N/S) of the rotor magnets requires an alternating polarity of current to rotate the stator vector. Like induction motors (the third means), synchronous motors are therefore *ac* (alternating current polarity: the original meaning of *ac*) motors. PMS motors are commonly referred to as “brushless dc motors” when they are not “dc motors” in method of torque production. The “dc” means that, when combined with a motor drive that produces an ac (bipolar current) excitation of the PMS electric machine, the user can supply a dc (static) power source and the motor-plus-drive will work.

The ambiguity in the expression “dc motor” results from its multiple meanings:

1. a means of torque production of the electric machine
2. the kind of power applied by the user to the motor as a system

Despite the possible confusion (which confused me when I started studying motors), the expression is common in the motor business. Hopefully, it will be replaced by *PMS motor*, the expression General Electric, for instance, uses.

Another source of confusion is in the use of the same mathematical symbols for different quantities. Because electronics, E&M, mechanics, and thermal processes are all modeled in power electronics, the same symbols from these different fields can appear in the same calculations. For instance, both voltage and speed, the magnitude of velocity, commonly use  $v$  as a symbol. To avoid confusion, speed is often relabeled as  $u$ , as in the above equation.

The preferred symbols used to label the main concepts of motor theory have been set out in newer books such as *Electromechanical Motion Devices*, by Purdue University professors Paul C Kraus and Oleg Wasynczuk (McGraw-Hill, 1989). For one, the “torque constant” ( $K_T$ ) is the direct-axis synchronous-reference-frame flux-linkage,  $\lambda_{ds}$ , of the rotor magnets referred to the mechanical (rotor) reference frame, and symbolized as  $\lambda_m^r$ . The prime refers the magnets to the stator windings. I have been using the more manageable symbol,  $\lambda_{me}$ , for the familiar quantity:

$$\ddot{e}_{me} = \left(\frac{P}{2}\right) \cdot \dot{e}_m^r$$

where,  $\lambda_{me}$  is referred to the mechanical reference-frame of the shaft by the pole-pairs,  $P/2$ .

Similarly, the “voltage constant” ( $K_V$ ) equals  $K_T$  for PMS motors when both are expressed in the mechanical rotating reference frame for a minimalist two-phase motor model. Then:

$$T = \lambda_{me} \cdot i_s \text{ and } v_\omega = \lambda_{me} \cdot \omega_{me}$$

### Particle Physicists Get it Right

High-energy particle physicists have averted confusion in naming new forces, fields, and their mediating particles by assiduously avoiding the re-use of already defined words (such as *force*). Instead, existing words from common experience, such as *color* and *charm*, which are not readily confused with existing physics language, are used. Ideally, new words, or words associated with purely fictional settings, (such as mathematician Lewis Carroll’s jabberwocky language from *Alice in Wonderland*) would avoid any possible confusion. For instance, color relates to the wavelength of visible electromagnetic energy, and to talk of quarks having a certain color could reintroduce confusion due to conceptual coupling. Historically, new words (or *neologisms*) usually were invented, such as *induction*, for something new requiring a name. This is the best approach for avoiding confusion.

In mathematics, conflation of meanings is evident in calling numbers “imaginary.” They are no more imaginary than *real* numbers, but since we learn early that the expression is not to be taken literally, confusion is avoided, as it is with the colors of quarks.

## Closure

For both clear communication and cognition, conceptually refined language – especially the meanings labeled by key words – requires distinct words for distinct meanings. E&M and motor theory in particular suffer from linguistic abuse. By knowing and avoiding ambiguous or misleading language, communications are both simplified and clarified.



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