Appendix 1 to the Proof of Evidence

Of

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On

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Basic Principles of Electric current and voltage

The basic principles of electric current and voltage are sometimes not easy to explain. With both voltage and current invisible to the human eye, it is not always simple to relate to these principles and their interactions with each other. One method of understanding these principles more simply is to draw an analogy to something more visible in everyday terms. The purpose of this Appendix is to help draw appropriate analogies to assist with the understanding of a few high level but key electrical concepts.

Voltage, Current, Resistance and Power

The concepts of voltage and current are sometimes described as being analogous to the flow of water in a system. If we consider voltage (or electrical potential) first, then this is often considered equivalent to a water tank full of water, connected on top of a pipe which runs vertically down. The higher the water tank is positioned, the higher the pressure in the pipe. In this case, voltage is analogous to the height of the water tank and to the pressure of the water within the pipes. The higher the water tank, the higher the ‘Voltage’ or in effect ‘Electrical Pressure/Potential’. Voltage is measured in Volts (V).

The flow of water within such a pipe is perhaps considered analogous to the amount of electrical Current flowing in a wire. The larger the pipe (analogous to larger conductor), the more water can flow through and so higher the water current. A larger pipe (or wire) can thus carry more water flow (or current). Electric current is measured in Amps (A).

Resistance can be more difficult to describe in terms of a water analogy. However, if we consider a water pipe with a certain diameter that for one short section contains a section of pipe with a narrower diameter, it can be understood that this smaller section will cause back pressure in the water pipe, causing the overall flow of water in the pipe to reduce. In electrical terms, the higher the resistance - the smaller the pipe. A higher resistance will therefore only allow a smaller amount of electrical current to travel along the conductor. The measurement of electrical resistance is Ohms (Ω).

In terms of the generation of electricity, the amount of Power (Watts) is related to the Voltage multiplied by the Current.   In effect, the higher the voltage then the lower the current needs to be in order to provide the same level of power. Using the water analogy again – the higher the water tank then the lower the current of that water needs to be to deliver the same amount of water to the tap.

For example, 100W of Power being delivered by a voltage of 50V will require 2A of Current (since Power = Voltage x Current). Delivering the same level of power (100W) but at a voltage of twice 50V, now 100V, means that the level of Current now will be half that previous at now 1A.

In summary, Voltage is analogous to the height and pressure of water in a tank, current is analogous to the flow of water within a pipe, resistance is analogous to the size of pipe used and Power is the product of Voltage and Current, analogous to the amount/volume of water supplied.

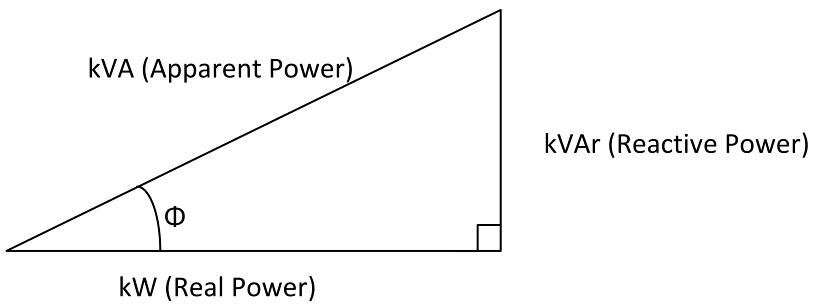
<u>MVA and Power factor</u>

In an AC[1] electrical system something called a power factor exists. Power factor is the ratio between the 'real power' in Watts (W), often expressed in kW (1,000W) or MW(1,000,000W)) and the 'apparent power' (total magnitude of power provided) in Volt Amperes (VA), often expressed in kVA or MVA.

Power factor is effectively a measure of how efficiently the power is being delivered/transmitted through a system. A power factor of 1 (or "unity") is the most efficient, with any other power factor resulting in the requirement for 'reactive power' (see below for an explanation of this term) in the system to be able to deliver the required level of power.

Reactive power is measured in Volt Amperes reactive VAr (often expressed in kVAr or MVAr). Some levels of reactive power occur naturally within a distribution network. This is because transformers require reactive power to to enable their function as a 'transformer' (i.e to increase or decrease the AC voltage in a system).

The mathematical relationship between power factor, kW, kVA and kVAr is illustrated below.



Power factor = (kW/kVA) = Cos Φ

Figure 1 – Power Factor triangle

As can be seen from Figure 1, as the angle Φ approaches zero, then the reactive power also approaches zero. For an angle Φ of zero, then there is zero reactive power and kW = kVA. The Cosine of Φ = 1 and so the power factor is 1 or unity.

As the power factor reduces, then for the same amount of Real power, the amount of Reactive Power would increase thus increasing the Apparent Power. This increase in Apparent Power would cause increased heating of conductors, transformers etc. This is shown in Figure 2 which illustrates the resultant powers for a fixed real power at two different power factors. It is seen that as the power factor reduces (angle Φ getting larger) then the other elements all increase.

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[1] AC means Alternating Current as the Voltage and Current alternate in a sinusoidal manner at 50hz (50 cycles per second) for the UK Transmission and Distribution Network.

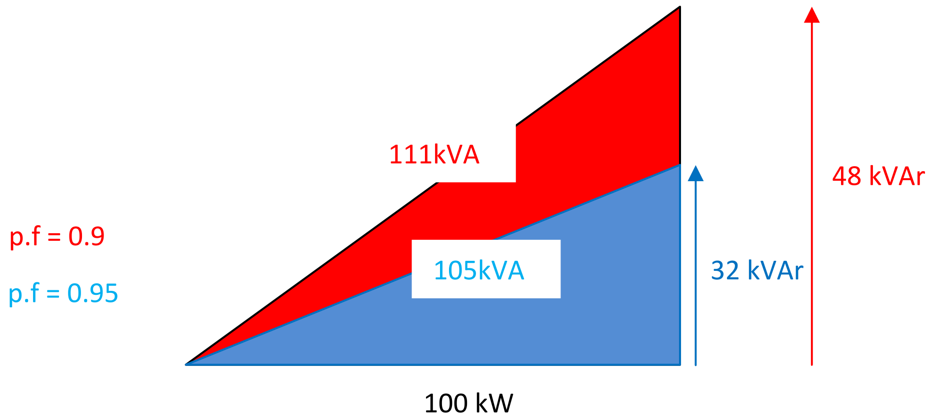

Figure 2 – Power Factor triangle for different power factors

To aid understanding of power factor further, the following analogy may assist.

Load and rope pull

In this analogy (Figure 3) a person is dragging a heavy load along the ground. The Real Power required to move the actual load in the forward direction is kW. Unfortunately, the person can't drag the load in a perfect horizontal plane and so the height of the person adds a little reactive Power (kVAr). The Apparent power (kVA) is therefore the vectorial sum of kW and kVAr. Clearly, for a fixed amount of kW required to move the heavy load, then a taller person would have to provide a larger Apparent power as the angle of the rope is to the object is larger (and so power factor smaller).

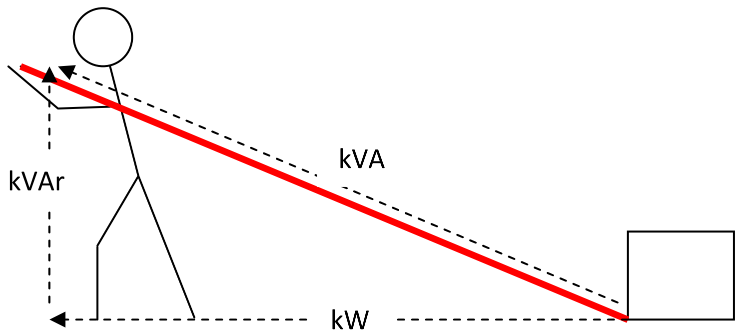

Figure 3 – Load and rope pull power factor analogy