KVAh Metering Basics

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Abstract

The pursuit of kVARh Metering, dates back to about 1915 and kVAh metering to about 1935. A lot of ground has been covered on these complex topics. However, it is only since the 1990's that digital signal processing improvements have led to working meters implementing the principles proposed then. Exhaustive computer simulations have also helped polish some rough edges of the original work. This paper explains the properties of kVAh for metering and suitability for applications.

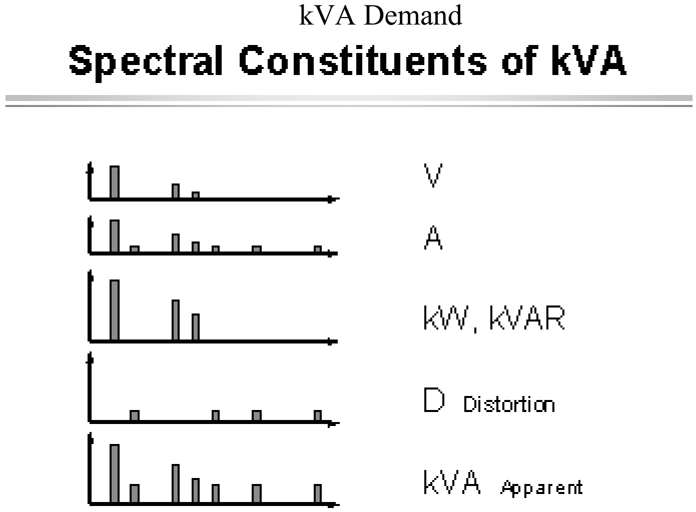
1. Revisiting kVA

India is in a unique position today. A large number of new meters being installed, while the latest in understanding of complex measurements and signal-processing technologies are available. Most other countries haven't had this opportunity.

Therefore, our standards can go a long way in breaking past legacy limitations.

kVA is already widely in use in Power Distribution and Billing:

- kVA Demand



- PF Penalties. PF = kW / kVA
- Sizing of Transformers and Distribution

Any ambiguous definitions are detrimental and must be corrected, irrespective of whether kVAh itself is directly billed

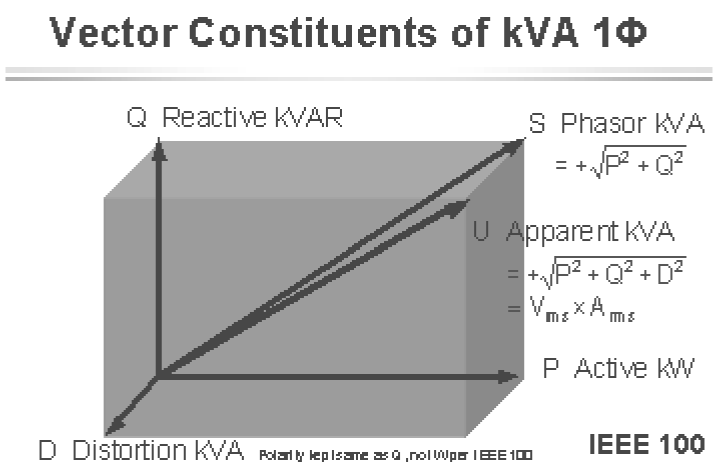
2. kVA Harmonic Spectrum

First, a quick look at what constitutes kVA (Apparent Power). We will stay clear of unnecessary formulae, relying instead on a “hands-on” graphical approach.

Note that Apparent kVA includes both the kW / kVAR as well as the Distortion components (Harmonics). There are 5 other definitions of kVA primarily based on subsets of any 2 out of these 3 spectra being included. The last definition, Arithmetic kVA is purely a Scalar quantity and not defined in terms of a Spectrum, but can contain many more bands than Apparent kVA.

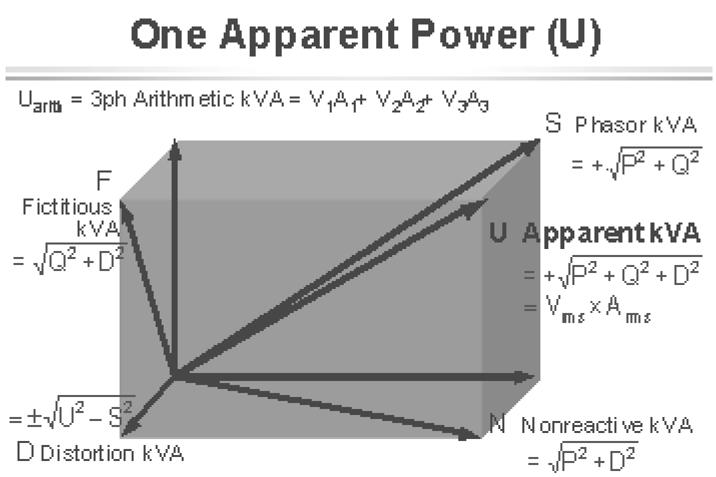
Measurement of Harmonic Current alone does not result in accurate measurement of kVA. Distortion Power must also be measured.

3. Vector Constituents of kVA



Present standards such as the CBIP88 have not included D in the definition of kVA. Without D, Apparent Power cannot be defined. So, CBIP88 basically defines S, which doesn’t include the Distortion power components.

4. Six kVAs



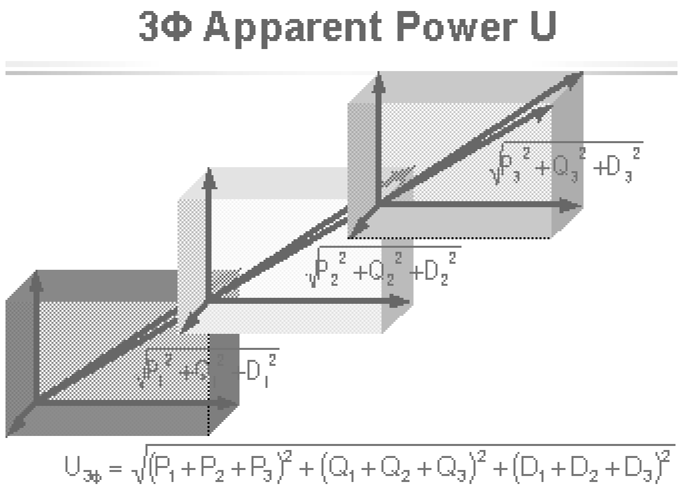
There are Six different quantities measured in units of kVA. Possibly, we often imply Apparent Power, which is one of the six defined quantities. The term “kVAh Metering” can therefore be misleading. Perhaps we should say “Apparent Energy Metering” or “Uh metering” for clarity?

CBIP88 defines kVA as the vector sum of kW and kVAR, meaning S (Phasor Power) and not U (Apparent Power). Therefore, it doesn’t include the Distortion Power term D.

For a single phase system, Apparent kVA is the vector sum of P, Q and D. It is also the simple product of Vrms and Arms.

In practice, Apparent and Arithmetic kVA are the most commonly used definitions for 3 phase measurements and we'll explore them further.

5. Three Phase Vector kVA



First, lets understand how the single-phase definition we've just covered, translates to 3 phases

For a 3 phase system, Apparent kVA is the vector sum of P, Q and D of all three phases. Imagine therefore, that the single-phase cubes of the previous slide are now stacked up corner to corner. The 3 phase Apparent kVA now stretches from the bottom most origin to the tip of the last VA vector. The resulting formula is now easy to visualise.

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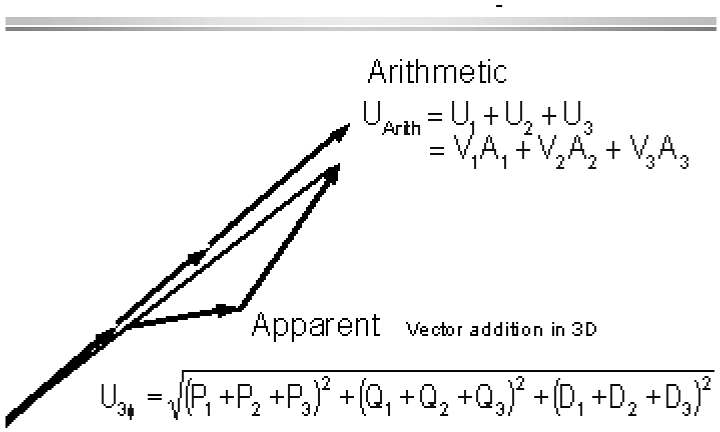


6. Three Phase kVA

There, now its clearer. 3 phase Arithmetic kVA doesn't care about the angles of the phase-wise VA vectors and stacks them straight up, end to end.

You will also see that this difference arises only in 3 phase calculations.

7. Three Phase Formula

Apparent kVA (U) vs Arithmetic kVA 3ph

- **Apparent kVA =**

$$U_{3\phi} = \sqrt{(P_1+P_2+P_3)^2 + (Q_1+Q_2+Q_3)^2 + (D_1+D_2+D_3)^2}$$

- **Arithmetic kVA =**

$$U_{Arith} = \sqrt{P_1^2+Q_1^2+D_1^2} + \sqrt{P_2^2+Q_2^2+D_2^2} + \sqrt{P_3^2+Q_3^2+D_3^2}$$
$$= U_1 + U_2 + U_3$$
$$= V_1A_1 + V_2A_2 + V_3A_3$$

Now that we've graphically seen the process, the formula is easier to understand

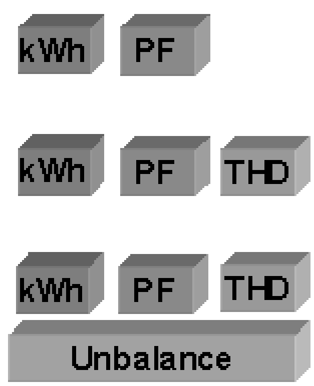
Consider $(a+b)^2$

Apparent kVA contains only the $a^2 + b^2$ terms, whereas Arithmetic kVA also contains the "2ab" terms. Which is why it is usually bigger. Arithmetic kVA is also very simple to compute

You will also see that this difference arises only in 3 phase calculations.

8. Apparent kVA vs Arithmetic kVA

- Traditional
  - » KWH + PF Penalty
- Apparent kVAh Metering
  - » + THD
- Arithmetic kVAh Metering
  - » + THD + Unbalance



Apparent kVA includes Wh, PF and THD revenue

■ a "Vector" quantity.

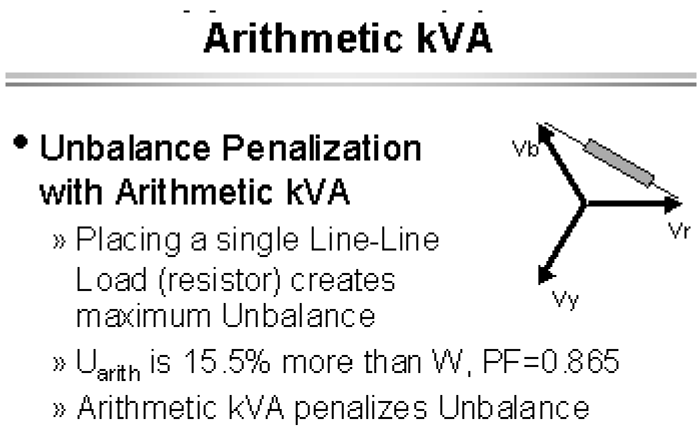
Arithmetic kVA in addition, includes "Unbalance" revenue

■ a Scalar quantity

■ $U_{arith} \geq U \geq S$.

■ U_{arith} is higher than U especially for Delta loads with unbalance

An Unbalance Penalty is also incorporated in Arithmetic kVA. Note in the accompanying example, that a resistive load is penalized as 0.86 PF by using Arithmetic kVA, for being highly unbalanced.



Arithmetic kVA simplifies metering. But meter measures only V, A, Freq, Arithmetic kVA, Arithmetic kVAh and Arithmetic kVA Demand

Arith kVA, kVAh and Demand are insensitive to:

- CT Polarity
- PT, CT Phase Shift errors
- Phase Sequence
- kVAh, Arith kVA Dmd

However, Apparent kVA is certainly affected by these conditions.

We have already seen that Arithmetic kVA is also simpler to compute. However, Apparent kVA is more “predictable” under unbalance and import/export conditions.

From earlier, we have also understood that this applies only to 3ph services. For single-phase services, there is no difference (Arithmetic kVA doesn’t exist).

9. Apparent kVA in Delta HT Systems

kVA (S) and PF in Delta systems do not directly measure Harmonic energy with

- Non-sinusoidal Waveforms
- Unbalanced Voltage Vectors / Loads

This deficiency is found today in HT billing of kVA Demand and PF values.

Apparent Power for unbalanced systems with non-sinusiodal voltages, is defined only for Star vectors (with respect to neutral). There is no equivalent computation for Delta systems where 3 voltages and 3 currents are not sampled. Under those conditions, mainly the Phasor kVA (S) can be used, as defined in CBIP88. However it doesn't include distortion power.

An alternative is to convert the Delta samples to Star samples before computation. This is possible with modern processors. However, tests of such meters with single-phase phantom sources need careful computation. Three-phase sources set-up to satisfy Kirchoff's Laws, are preferred.

Star vectors are also better behaved. Many users are more comfortable seeing Phase-wise PF = 1 with resistive load, than 0.86 with the same resistive load with Delta 2 Element measurement.

10. Application Suitability

Arithmetic kVA is suitable for:

- Domestic (1ph) and Commercial billing
- Simplicity in meeting the cost of service

Apparent kVA is suitable for:

- Industrial and Grid metering (Energy Balancing, Import/Export conditions)
- Not possible for 1ph services

The important point is, is it available in the meters?

11. Conclusion

This paper has explained the principles underlying the Six different "Volt-Ampere" products. We delved a little deeper into Apparent kVA and Arithmetic kVA. Though certain Polarity subtleties of Four Quadrant metering of Power parameters have been left out for the sake of clarity, one is hopeful that enough ground has been covered to assist in prudent and effective application of the term "kVA".