Newtons4th Ltd
office@newtons4th.com
www.newtons4th.com

APPLICATION NOTE 36
## 6 & 7 phase motor drive analysis

Introduction

Given the advantages of low start up power demand, controlled acceleration, adjustable speed without mechanical gearing and higher efficiency; variable frequency drives (VFD's) represent a rapidly increasing proportion of electrical motor applications. In common with many fast growing technologies, the use of variable frequency drives is no longer limited to industrial or specialist applications, with modern domestic electrical devices from white goods to power tools now commonly using VFD technology.

In the same way that switched mode power supply technology increased the need for power analysis measurement equipment with sufficient accuracy to verify ever increasing efficiency, the increased efficiency of VFD's combined with the complex wideband voltages generated by these devices, is taking the requirements of inverter and motor testing beyond the ability of measurement equipment that satisfied the needs of conventional AC motor applications.

Measurements being made may focus on Motor efficiency, VFD efficiency or a complete system from the AC power source to mechanical power output but in any case, multiple points of measurement will be required. Where an application is steady state and highly repeatable, it is practical to make sequential measurements. However, if as in most cases, absolute stability cannot be assured or when load conditions will change as we can generally expect in a VFD application, simultaneous measurement of electrical to electrical and/or electrical to mechanical efficiency requires instrumentation that has been designed to handle the complex nature of this demanding measurement environment.

System efficiency with 6 phase analysis

In the diagram below, Rectifier, Inverter and Motor efficiency are measured with a 6 phase measurement instrument:

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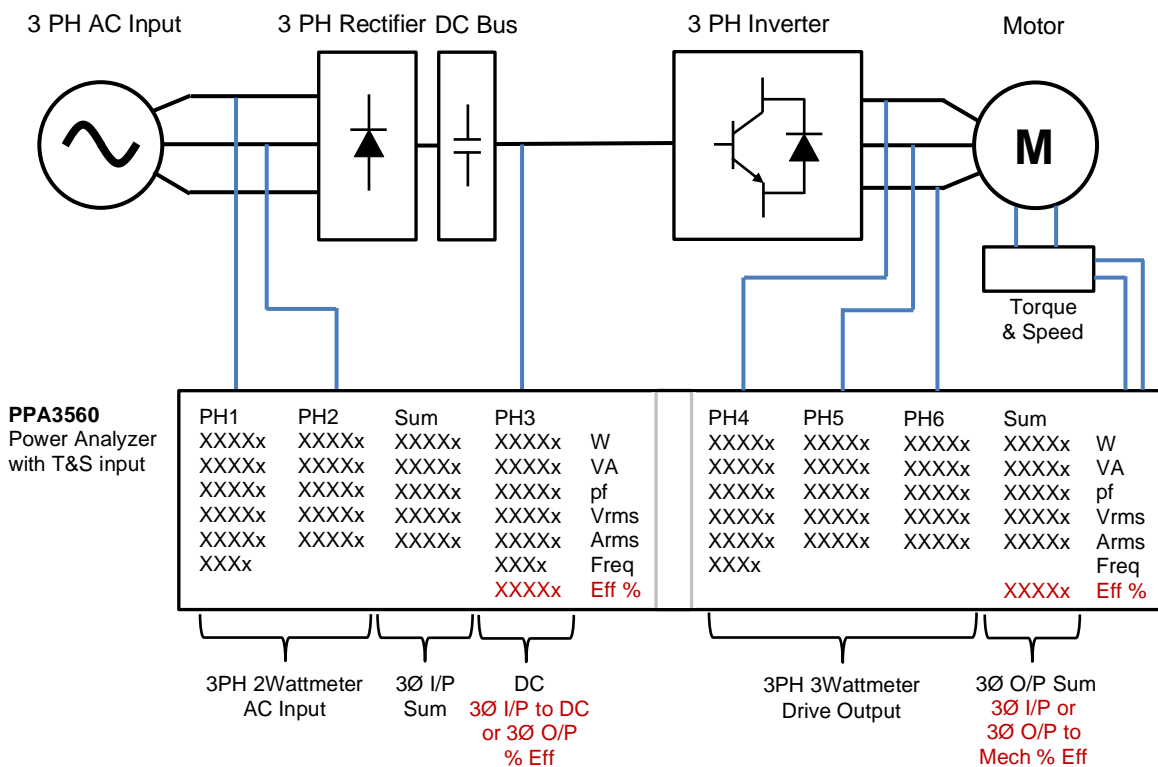
Why a 6 phase instrument?

It can be seen that with 6 power measurement channels plus torque and speed inputs, it is possible to quantify total 3 phase input power, DC bus power, 3 phase output power and the mechanical power. It is partly for this reason that 6 power measurement channels are a common option for power measurement products targeted at this application.
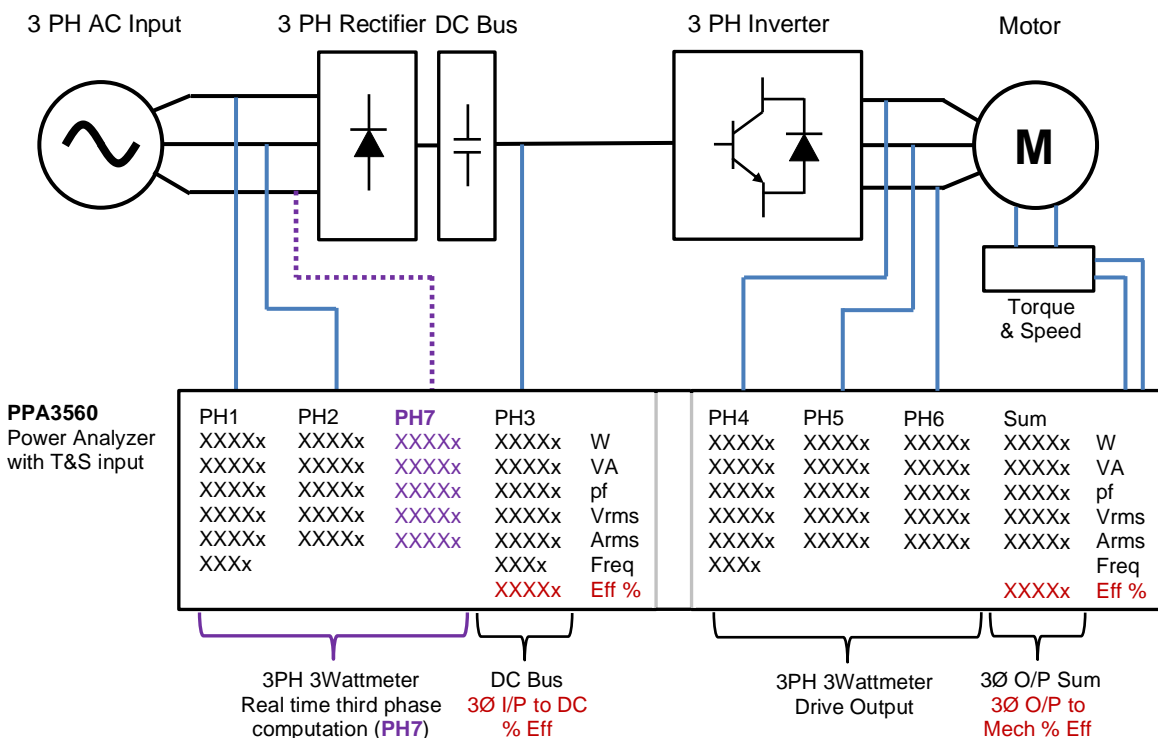
Where it is only necessary to quantify total electrical input and total electrical output i.e. when there is no need to measure the DC bus power, both the 3 phase input and 3 phase output can be configured with full a 3 Wattmeter measurement method. This allows a user to see the individual power contribution from each of the three phases. However, since the individual phase power of the inverter output is usually of much greater interest than each phase of the relatively simple AC supply, the input is commonly measured using a 2 Wattmeter technique that will derive exactly the same total power on a three wire system as the 3 Wattmeter method while releasing a measurement channel than can be used for DC bus power measurement or other quantities of interest such as speed, vibration, temperature etc.

At this point, it is worth reminding ourselves that contrary to statements sometimes raised in relation to three phase measurement techniques on a three phase three wire power system, a correctly implemented 2 wattmeter measurement technique will achieve exactly the same sum power measurement that would be derived from a 3 wattmeter technique. This remains true irrespective of magnitude, phase angle or harmonic imbalance of the three phase system being measured. So, while it can certainly be interesting to know the relative power contribution of each phase and this can be provided with 3 phase 3 wattmeter connection as mentioned above, the 2 wattmeter method will result in exactly the same total power measurement.

Can a 6 phase instrument give 7 phase results?

Yes. Given the nature of vector interaction between each phase of a 3 phase 3 wire system, a measurement system with sufficient real time processing power can derive the third phase voltage, current and power values when connected in 2 wattmeter configuration with real-time 2 wattmeter to 3 wattmeter conversion.

In the diagram below, we illustrate 2 to 3 wattmeter conversion where the computed phase is shown as **PH7**.

	APP037 – 6 & 7 phase motor drive analysis	July 2021	Doc ref: D000329 2
	Newtons4th Ltd 1 Bede Island Road Leicester LE2 7EA UK		Tel: +44 (0)116 2301066

Newtons4th Ltd
office@newtons4th.com
www.newtons4th.com

3 phase 2 wattmeter to 3 phase 3 wattmeter conversion

Nomenclature:

$Vdn(t)$ = voltage of phase n relative to phase 3
$Vs(t)$ = voltage of "star point" relative to phase 3
$Vsn(t)$ = voltage of phase n relative to "star point"
Zn = load impedance of phase n
Z = parallel impedance of Z1, Z2 and Z3
$An(t)$ = current flowing in phase n
$Wdn(t)$ = power in phase n measured in 3p2W
$Wsn(t)$ = power in phase n measured in 3p3W

Voltage computations:

Consider the "star point" voltage relative to phase 3-line voltage, by superposition theorem:

Vs(t) = Z (Vd1(t)/Z1 + Vd2(t)/Z2)

If Z1 = Z2 = Z3, then

Vs(t) = (Vd1(t) + Vd2(t)) / 3

Now,
Vs1(t) = Vd1(t) − Vs(t)
= Vd1(t) − (Vd1(t) + Vd2(t)) / 3
= (2.Vd1(t) − Vd2(t)) / 3

Similarly,
Vs2(t) = (2.Vd2(t) − Vd1(t)) / 3

Vs3(t) = 0 − Vs(t)
= − (Vd1(t) + Vd2(t)) / 3

Note that these computations require only that the phase load impedances are the same and that there are no other voltage sources influencing the star point.

Current computations:

Phase 1 current and phase 2 current are directly measured; phase 3 can be computed by Kirchoff's current law:

A3(t) = − A1(t) − A2(t)

This assumes that there are no other sources of current influencing the star point

Power computations:

Ws1(t) = Vs1(t) x A1(t)
= (2.Vd1(t) − Vd2(t)).A1(t) / 3
= (2.Wd1(t) − Vd2(t).A1(t)) / 3

Ws2(t) = Vs2(t) x A2(t)
= (2.Vd2(t) − Vd1(t)).A2(t) / 3
= (2.Wd2(t) − Vd1(t).A2(t)) / 3

Ws3(t) = Vs3(t) x A3(t)
= (− Vd1(t) − Vd2(t)) x (− A1(t) − A2(t)) / 3
= (Wd1(t) + Vd1(t).A2(t) + Vd2(t).A1(t) + Wd2(t)) / 3

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To confirm the power formulae, consider the total power ((t) omitted for clarity):

Total power = Ws1 + Ws2 + Ws3
= (2.Wd1 – Vd2.A1 + 2.Wd2 – Vd1.A2 + Wd1 + Vd1.A2 + Vd2.A1 + Wd2) / 3
= Wd1 + Wd2

All these computations are based on instantaneous values and require only that there is no other electrical source acting on the star point of a load and that, as we might expect, the impedance of each phase of the AC source are comparable.

Example screenshots from a PPA3560 Precision Power Analyzer in 7 phase measurement mode:
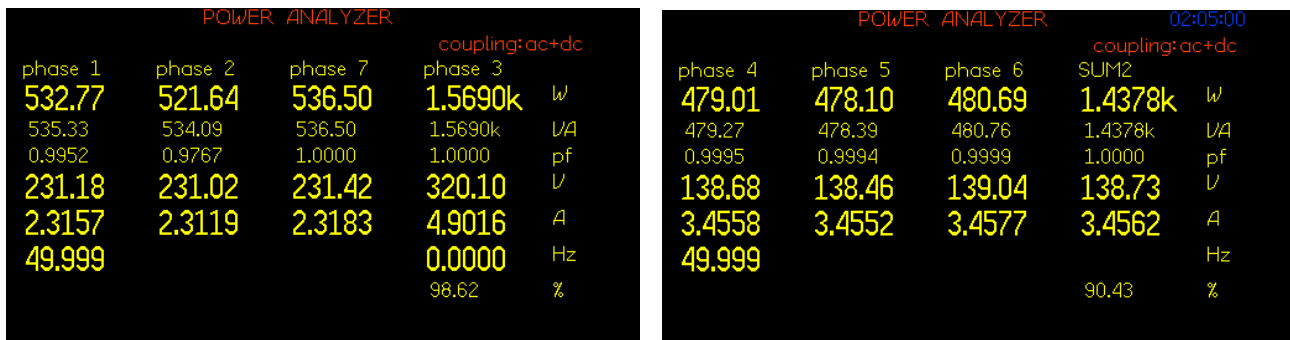
Note that "Phase 7" is Phase 3 of the three phase input waveform, with Watts, VA, pf, V and A all calculated for the simulated phase.

Conclusion

The increasing complexity of modern VFD applications require multi-channel power measurement products to achieve meaningful power analysis.

Modern power measurement instruments with appropriate sampling techniques and processing power can provide real time high accuracy measurements in 6 or 7 phase power measurement applications.