Application of three-phase AC power supply:

Simulating three-phase imbalance

Keywords:
Voltage Unbalance, Eliminates phase imbalance Power Supply, three-phase unbalance + reverse phase and lack of phase monitoring relay (Monitors voltage asymmetry, phase sequence and phase loss Relay), Induction Motor, VFD: Variable-frequency Driver

Foreword:
An ideal three-phase AC power system has three-phase voltages with the same amplitude, phase angles differing by 120 degrees from each other, and a three-phase infinite bus. But reality is often cruel. Three-phase systems have the issue of three-phase unbalance. This article will discuss the definition of three-phase unbalance, the harm of three-phase unbalance and how to use three-phase AC power to simulate a three-phase unbalanced test environment to facilitate testing of related applications. These applications include power supplies to solve three-phase unbalance; three-phase unbalance + reverse phase and lack of phase monitoring relay; three-phase induction motors and frequency converters to control motors.

Application of low voltage three-phase power distribution system

Taking Taiwan as an example, the three-phase low-voltage power distribution system includes 3Φ3W (220V V-V connection) and 3Φ4W (220/380V), which together account for 16.4% of the overall electrical load (see Table 1). The most common applications are motors, pumps, fans, air compressors and other applications.

User type	Number of users	Load ratio
Extra high voltage (161KV/69KV)	626	32.4%
High voltage (11.4/22.8KV)	25,453	28.8%
Power distribution system 1Φ3W (110/220V)	12,972,935	22.4%
Power distribution system 3Φ3W (220V V-V connection)	**237,677**	**10.2%**
Power distribution system 3Φ4W (220/380V)	**835,493**	**6.2%**
Subtotal	14,072,184	100.00%

Table1: Taiwan's electricity user types and load structure in 2022 (electricity consumption in 2022 is approximately 279.45 billion kWh) [Reference 1]

Definition of three-phase unbalance

Three-phase unbalance refers to the fact that in a three-phase system, the effective values of the fundamental waves of line voltages are not equal to each other or the phase angles between line voltages are not equal to each other.
The definitions of three-phase voltage unbalance are mainly divided into three types: "True Definition", "NEMA [Note 1] Definition" and "IEEE [Note 2] Definition". The calculation method is as shown in Table 2:
Example:
Taking the line voltages as 380V, 390V, and 370V as an example, using the NEMA definition formula to calculate, the average line voltage is 380V, and the maximum deviation from average line voltage is 380-380=0; 390-380=10, 380-370=10, and the maximum variation of 10 is adopted
Voltage imbalance rate=10/380=2.63%

Definition	Formula
True definition	$\%VUF = \frac{\text{Negative} - \text{Sequence Voltage}}{\text{Positive} - \text{Sequence Voltage}} \times 100\%$ (Negative-Sequence Voltage) (Positive-Sequence Voltage)
NEMA definition	$\%LVUF = \frac{\text{max voltage deviation from the avg. line voltage}}{\text{avg. line voltage}} \times 100\%$
IEEE definition	$\%LVUF = \frac{\text{max voltage deviation from the avg. phase voltage}}{\text{avg. phase voltage}} \times 100\%$

Table 2: Formulas for three definitions of three-phase voltage unbalance. [References 1 and 2]

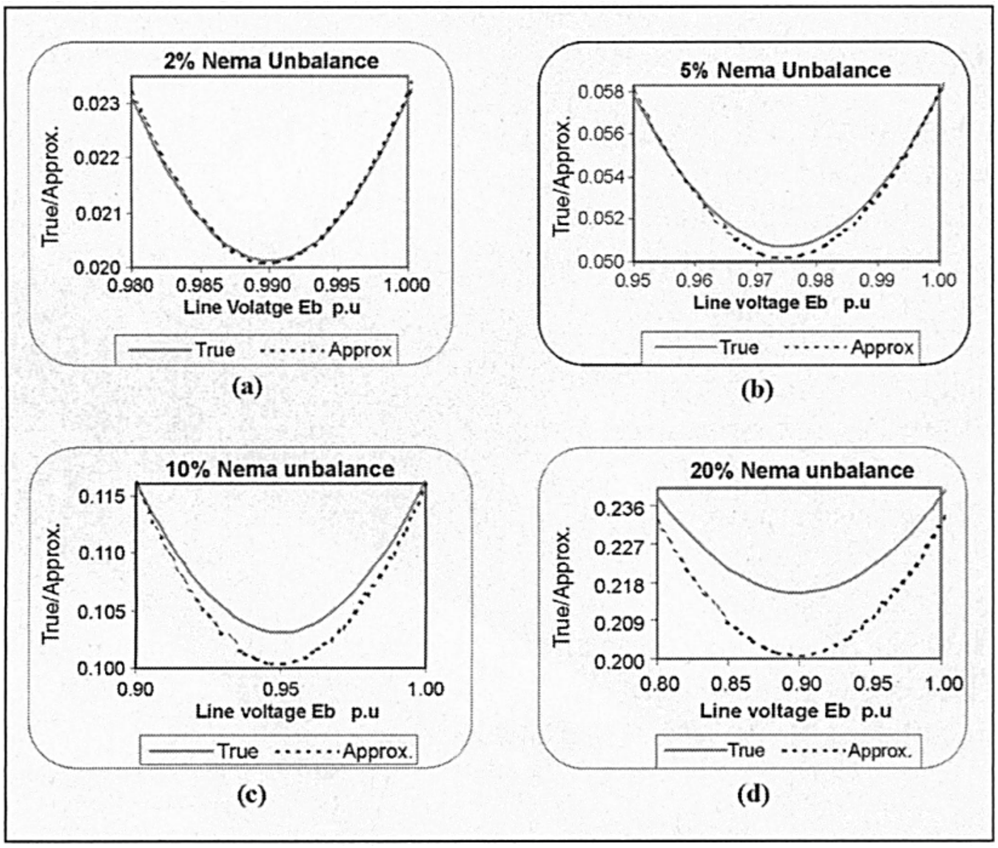

Figure1: The relationship between NEMA and true definition under different line voltages (taking NEMA 2%, 5%, 10% and 20% as examples) [References 1 and 2]

NEMA definition	True definition	Approximation formula
%	%	%
2	2-2.3	2-2.3
5	5-5.8	5-5.8
10	10.3-11.6	10-11.6
20	21-23.8	20-23.2

Table 3: The approximation formula between the NEMA definition and the true definition is sorted out from Figure 1 [References 1 and 2]

The "true definition" is the ratio of the negative sequence voltage component to the positive sequence voltage component (%VUF). Since it cannot be directly obtained through actual measurement, the "NEMA definition" of measuring line voltage imbalance rate (%LVUR) is often used in practice. ” or measure the “IEEE definition” of phase voltage imbalance rate (%PVUR) to approach the “true definition”. American standard ANSI C84.1_C.2 recommends that the voltage imbalance rate be below 3% (no load)

Causes of three-phase voltage unbalance

The main cause of imbalance: Single-phase load. One-phase large-capacity loads such as electrified railways, electric arc furnaces, electric welding machines, etc. have unreasonable capacity and electrical location distribution in the system

The dangers of three-phase unbalance

Unbalanced power supply voltage will increase heat loss and cause vibration in electrical equipment (such as motors). According to two documents by Bryan Glenn [Reference 3] and Edvard Csanyi [Reference 4], both pointed out that for every 1% voltage imbalance generated, 6% to 10% of current imbalance will be generated. Taking a 5hp, 1,725rpm, 230V, 3-phase 60Hz induction motor as an example, the impact of unbalanced voltage on motor performance is shown in Table 4

Characteristics	Performance		
Average voltage	230	230	230
Voltage imbalance rate	0.3	2.3	5.4
Current imbalance rate	0.4	17.7	40.0
Temperature rise,℃	0	30	40

Table 4: The impact of voltage imbalance on 3-phase induction motor

Products must be able to withstand three-phase unbalance or provide preventive or protective measures

The American standard ANSI recommends that the voltage imbalance rate be below 3% (no load), which also means that the product must be able to withstand this regulation. The AC power supply is used to simulate three-phase unbalanced voltage to test the DUT. The test scenarios include design verification in the R&D stage and aging test in the quality assurance stage.
It can also be prevented or protected through products such as power supplies that eliminate three-phase imbalance, three-phase imbalance + reverse phase and lack of phase monitoring relays (Monitors voltage asymmetry, phase sequence and phase loss Relay). For example: OMROM's S8VK-WA and K8AK-PA [Reference 4].

The above applications require three-phase AC power supply to provide three-phase unbalanced voltage; change the phase angle; change the phase sequence for testing.

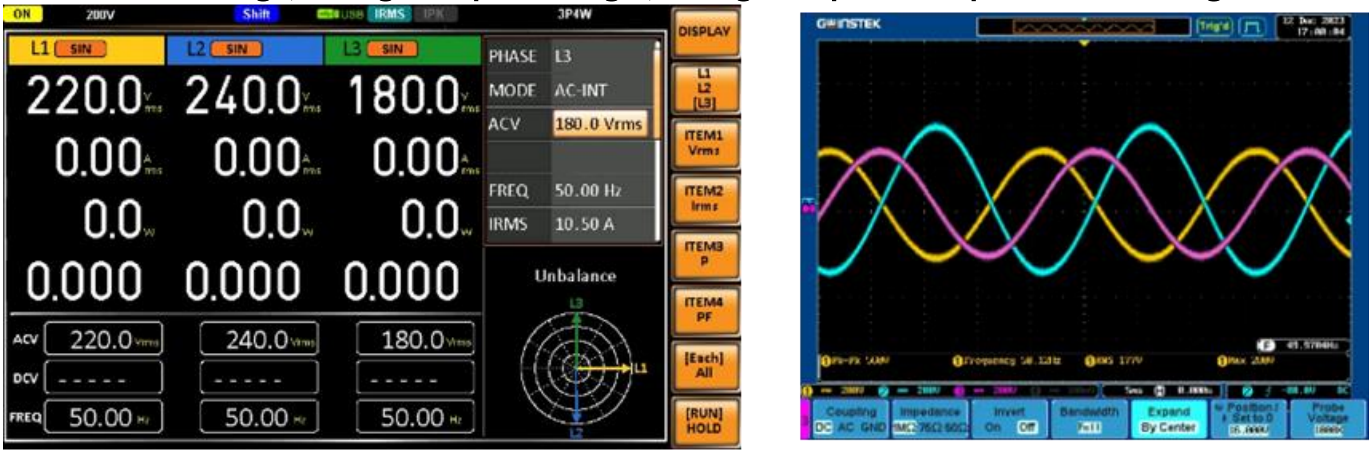

Figure 2: GW Instek ASR-6000 series AC power supply outputs unbalanced three-phase voltage display (left), and the oscilloscope measures the output waveform (right)

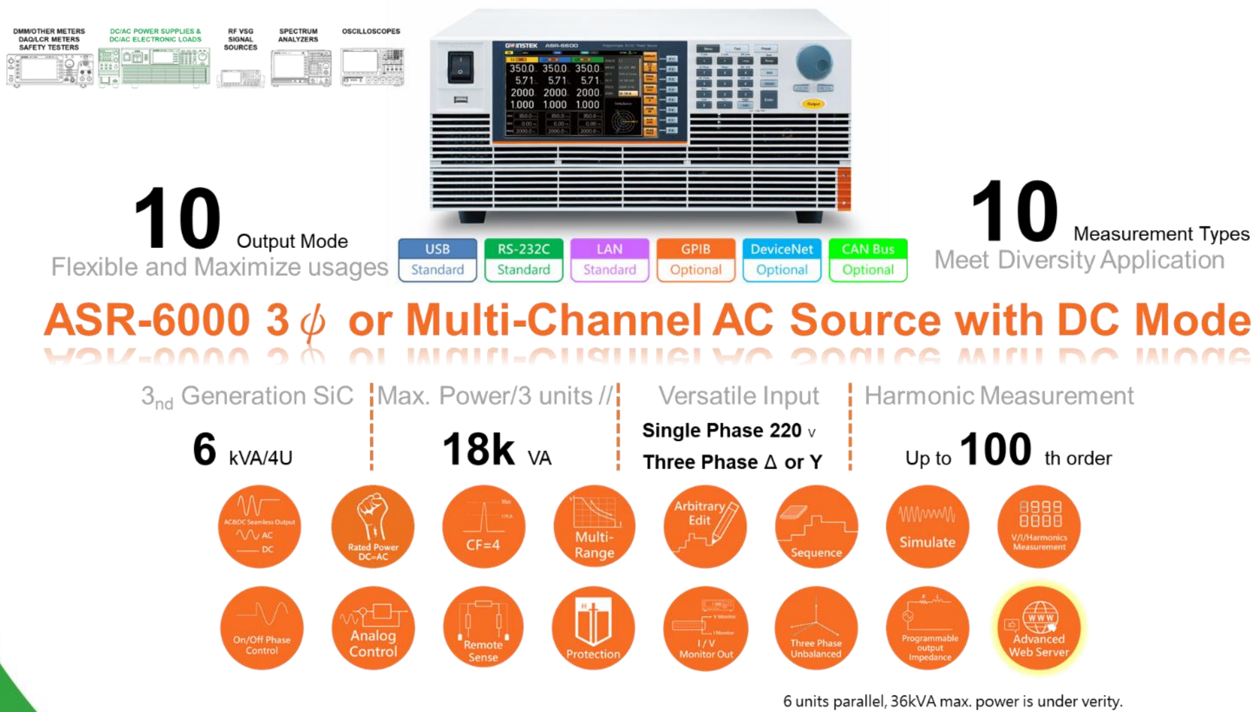

Figure 3: Important features of the ASR-6000 series

Annotation:

1：NEMA：National Electrical Manufacturers Association

2：IEEE：Institute of Electrical and Electronics Engineers

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