ENGINEER

international scientific journal

ISSUE 2, 2025 Vol. 3

E-ISSN
3030-3893

ISSN
3060-5172

A bridge between science and innovation

TOSHKENT DAVLAT TRANSPORT UNIVERSITETI
Tashkent state transport university

ENGINEER

A bridge between science and innovation

E-ISSN: 3030-3893

ISSN: 3060-5172

VOLUME 3, ISSUE 2

JUNE, 2025

engineer.tstu.uz

TASHKENT STATE TRANSPORT UNIVERSITY

ENGINEER

INTERNATIONAL SCIENTIFIC JOURNAL
VOLUME 3, ISSUE 2 JUNE, 2025

Founder of the international scientific journal “Engineer” – Tashkent State Transport University, 100167, Republic of Uzbekistan, Tashkent, Temiryo‘lchilar str., 1, office: 465, e-mail: publication@tstu.uz.

The “Engineer” publishes the most significant results of scientific and applied research carried out in universities of transport profile, as well as other higher educational institutions, research institutes, and centers of the Republic of Uzbekistan and foreign countries.

The journal is published 4 times a year and contains publications in the following main areas:

- Engineering;
- General Engineering;
- Aerospace Engineering;
- Automotive Engineering;
- Civil and Structural Engineering;
- Computational Mechanics;
- Control and Systems Engineering;
- Electrical and Electronic Engineering;
- Industrial and Manufacturing Engineering;
- Mechanical Engineering;
- Mechanics of Materials;
- Safety, Risk, Reliability and Quality;
- Media Technology;
- Building and Construction;
- Architecture.

Tashkent State Transport University had the opportunity to publish the international scientific journal “Engineer” based on the **Certificate No. 1183** of the Information and Mass Communications Agency under the Administration of the President of the Republic of Uzbekistan. **E-ISSN: 3030-3893, ISSN: 3060-5172.** Articles in the journal are published in English language.

Analysis of measurement of harmonic power of non-sinusoidal currents in modern electrical networks

T.U. Kurbaniyazov[1][a], A.B. Bazarbayev[1][b]
[1]Nukus State Technical University, Nukus, Republic of Karakalpakstan, Uzbekistan

Abstract: Precise measurement of power and other AC parameters is essential across all levels of the electrical power system, benefiting both suppliers and consumers. Traditionally, measurement devices have been designed under the assumption that voltage sources produce sinusoidal waveforms and that loads are linear, resulting in sinusoidal currents. However, with the growing prevalence of non-linear loads and the increasing demand for measurement accuracy, these assumptions often no longer hold true. As a result, there is a growing focus on understanding how non-linear loads affect measurement accuracy and on developing new instruments capable of operating reliably under non-sinusoidal conditions in power networks. This study contributes to that effort by developing and validating a digital sampling wattmeter designed for accurate measurement under non-sinusoidal conditions, meeting standard laboratory precision requirements. It also seeks to enhance understanding of the challenges involved in measuring in such environments.

Keywords: Nonsinusoidal three-phase current, sensors, metering methods, active and reactive power, harmonic current

1. Introduction

The concept of measuring and calculating electrical power using digital sampling of voltage and current has been explored for quite some time, as noted by Clark and Stockton in 1982 [1]. One key benefit of this method is its ease of calibration, along with the high precision of digital multiplication, which avoids the linearity issues sometimes found in analog-based power meters. Additionally, digital sampling allows for accurate power measurement even in non-sinusoidal conditions and facilitates the analysis of power contributions from individual harmonics.

In the past, digital sampling faced significant challenges due to the high speed and accuracy required for analog-to-digital conversion and real-time processing. However, over the past few decades, advancements in sampling and ADC (Analog-to-Digital Converter) technologies have significantly improved both precision and sampling rates. Today, even highly accurate voltmeters utilize these methods. Additionally, many of these instruments are equipped with standard computer interfaces, greatly simplifying data acquisition. They also incorporate the necessary electrical isolation between the voltage input, current input, and the computer, addressing key safety and performance concerns. As a result, such instruments are now highly suitable for fast and precise digitization, making them ideal for power measurement applications.

2. Research methodology

Mathematical notations

This review of proposed definitions of power under nonsinusoidal conditions encompasses a wide range of studies by authors from various countries and time periods. As a result, there is significant variation in the terminology and mathematical notation used across these sources. While some of the original notations are retained, this paper primarily adopts a more standardized set of symbols to improve clarity and consistency. Instantaneous values and time-dependent functions are represented using lowercase letters, whereas RMS and mean values are denoted by uppercase letters. Additionally, no specific distinction is made between scalar and complex quantities.

For the general case the active (mean) electrical power is:

$$P = \frac{1}{T}\int_T^{\infty} u * i * dt \qquad (1)$$

where T is the time of interest or the observation time, or for periodic signals, the period time. In an ideal power system, the voltages and currents are (purely) sinusoidal with a frequency of 50 Hz or 60 Hz. However, non-ideal characteristics of real-life power system components and non-ideal loads will cause distortion. Currents and voltages will be nonsinusoidal and will contain harmonics. In most cases, the currents and the voltages will still be (approximately) periodic with a fundamental frequency of 50 Hz or 60 Hz. If the voltage and current both are periodic functions of time with the same period T, the voltage and current can both be expressed as a Fourier series and the power can be defined as [2]:

$$P = \sum_n U_n * I_n * \cos\varphi_n \qquad (2)$$

where n is an order for which both the voltage and current harmonics exist, and φ_n is the phase angle difference between u_n and i_n. Further, for the special case where both the voltage and the current are sinusoidal the active power can be expressed by the familiar equation [2]:

$$P = U * I * \cos\varphi \qquad (3)$$

These definitions are grounded in the physical principles of electrical power and energy, which can be converted into other forms such as thermal or mechanical energy, and subsequently measured through corresponding physical effects. As a result, Equations (1) through (3) are universally accepted, with no disputes arising - whether in the general case or in specific scenarios involving sinusoidal or nonsinusoidal periodic signals [2,3].

Apparent and reactive powers, on the other hand, are not based on a single, well defined, physical phenomenon as the

[a] https://orcid.org/0000-0001-5296-4600
[b] https://orcid.org/0009-0002-2617-9320

active power is. They are conventionally defined quantities that are useful in sinusoidal or near sinusoidal situations. For sinusoidal voltages and currents reactive power is defined as:

$$Q = U * I * \sin\varphi = \sqrt{S^2 - P^2} \quad (4)$$

and apparent power is defined as:

$$S = UI = \sqrt{P^2 + Q^2} \quad (5)$$

At nonsinusoidal conditions there is, more or less, a general agreement on using [4]:

$$S = UI \quad (6)$$

It is usual to denote this expression of reactive power by Q_B. The power triangle is generally not satisfied by this definition so another quantity D must be defined to determine the relation between apparent power, reactive power and active power:

$$D^2 = S^2 - P^2 - Q^2 \quad (7)$$

However, the definition proposed by Budeanu is generally regarded as impractical for real-world applications [3, 4]. Moreover, as previously mentioned, reactive power is not derived from a single physical phenomenon; rather, it is a mathematically defined quantity. Despite this, it possesses several valuable characteristics and meaningful physical interpretations, particularly under sinusoidal conditions [5].

Preferred measurement and metering methods

Modern and future digital power and energy meters equipped with frequency analysis capabilities open up new opportunities for power measurement. Traditional metering approaches can be revised and enhanced, overcoming the limitations and ambiguities of older equipment—particularly when measurement quantities are properly defined for the actual nonsinusoidal conditions present. To ensure meaningful and consistent results, it is important to identify the most appropriate measurement methods and quantities, distinguishing them from the wide range of theoretical possibilities. This chapter explores the pros and cons of a metering approach that distinguishes the fundamental power components from the remaining parts of the apparent power.

Over the past fifty years, extensive theoretical research has been conducted on power components in nonsinusoidal conditions. In parallel, specialized instruments for power quality measurement have become increasingly widespread. However, the high cost of meters capable of performing the spectral analysis required for measuring many of the proposed new quantities has limited their adoption in revenue metering and permanent installations. With ongoing advancements, sampling techniques are expected to become standard in meters designed for stationary use. As a result, it is now necessary to critically examine the practical applicability of nonsinusoidal power theories.

In power theory research, the primary emphasis has been on identifying the most theoretically accurate or optimal concept [1]. In addition, various specialized power concepts have been introduced to address specific situations or applications [2]. A common approach in many proposed definitions of power components involves decomposing the current into orthogonal components. Among these, the active current i_a is typically defined as the component that would produce active power if the load were purely resistive [3].

$$i = i_a + i_n = \frac{P}{U^2} u + i_n \quad (8)$$

The rest term in can be considered as a generalised reactive or, preferably, non-active current. Since i_a and i_n are orthogonal, the apparent power can be calculated from the rms currents I_a and I_n and the rms voltage, and divided into active and non-active power:

$$S^2 = U^2 * (I_a^2 + I_n^2) = P^2 + N^2 \quad (9)$$

The non-active portion of the current can be further decomposed into additional orthogonal components. When these squared current components are multiplied by the squared voltage, as shown in Equation (9), the result is a set of multifrequency power components. These components can be aggregated - much like the active and reactive power components in sinusoidal conditions - to form the squared apparent power.

From a power system engineering perspective, it is often practical and appropriate to separate the voltage and current - herefore, the power - into the fundamental component and the unwanted harmonic components. This division allows for distinguishing the fundamental power components from the remainder. This approach has been acknowledged by several authors, who have proposed a power definition based on these principles [4].

The suggested definition starts by dividing the rms voltage and the rms current into fundamental and harmonic parts [5,6]:

$$U^2 = U_1^2 + U_N^2 = U_1^2 + \sum_{n>1} U_n^2 \quad (10)$$

$$I^2 = I_1^2 + I_N^2 = I_1^2 + \sum_{n>1} I_n^2 \quad (11)$$

The voltage and current are then multiplied to form the apparent power, and the power components (for balanced circuits) are suggested as:

$$S^2 = S_1^2 + S_N^2 = P_1^2 + Q_1^2 + P_N^2 + N_N^2 + (U_1 I_N)^2 + (U_N I_1)^2 \quad (12)$$

where

$$S_1^2 = P_1^2 + Q_1^2 = (U_1 I_1 \cos\varphi_1)^2 + (U_1 I_1 \sin\varphi_1)^2 \quad (13)$$

$$P_N = \sum_{n>1} U_n I_n \cos\varphi_n \quad (14)$$

$$N_N^2 = S_N^2 - P_N^2 = \sum_{n>1} U_n^2 \sum_{n>1} I_n^2 - P_N^2 \quad (15)$$

$$(U_1 I_N)^2 = U_1^2 \sum_{n>1} I_n^2,\ (U_N I_1)^2 = I_1^2 \sum_{n>1} U_n^2 \quad (16)$$

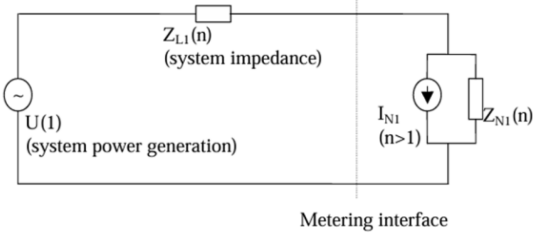
N_N is a harmonic rest term and (16) describes the cross-products between fundamental and harmonic parts. The difference between the apparent power division described above and other suggested power definitions may seem subtle but is quite substantial. The most obvious difference, is that the (total) active power no longer is one of the power components. P1 is one of the components, and P_N is one, and the active power is $P=P_1+P_N$, but $P_2 \neq P_1^2 + P_N^2$ and can not be put into (12). However, as a supplement to the apparent power split above the nonactive power is given as:

$$N = \sqrt{S^2 - P^2} \quad (17)$$

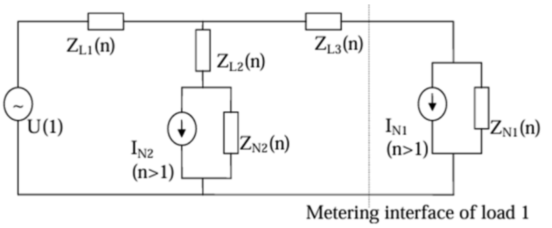
A common and widely used method for dividing the responsibility and costs of power quality issues, including reactive power, is to assign responsibility for voltage to the power distributor and responsibility for current to the consumer [7-9]. This approach functions effectively as long as the voltage and current characteristics do not interact significantly, allowing for a clear separation between cause and effect.

The magnitude of the fundamental quadrature current is primarily determined by the load characteristics, which can be measured as reactive power in the classical sense. As a result, the responsibility for this quadrature fundamental current can be easily assigned to the power consumers. However, a situation may arise where billing for quadrature fundamental current based on classical reactive power metering is unfair. For instance, if two nearby customers have opposing loads - one inductive and the other capacitive - both might be charged for reactive power that ultimately cancels out and causes no issue for the distributor. This situation is rare, particularly given the scarcity of large capacitive loads, and can usually be handled as an exception.

Harmonic current is primarily considered a distribution issue rather than a transmission problem. Most of the challenges associated with harmonics are of a local nature, as the interaction between different loads can lead to current cancellation, which in turn reduces the overall harmonic current level from groups of loads. This localized effect makes harmonic mitigation more manageable within the distribution network, rather than requiring large-scale changes at the transmission level. Figure 1 and Figure 2 demonstrates the metering problems due to the interactions between loads, especially between load currents. From Figure 3 it is evident that the relative sizes of the impedance of the lines and/or the impedance of transformers, Z_{L1}, Z_{L2} and Z_{L3}, will very much determine the current level in the metering point of a load. Distribution transformers often play a significant role in determining the impedance seen by harmonic current sources and can act as a barrier to harmonic currents to some extent. As a result, consumers who share a distribution transformer are more likely to experience greater harmonic current interaction, leading to higher harmonic current amplitudes at their metering points, compared to consumers who are not sharing the same transformer. This current cancellation and interaction are especially noticeable for harmonics of order greater than 10, where the phase angles naturally spread more widely, leading to more pronounced effects [10].



a) simple load-source model for the case of one large non-linear load



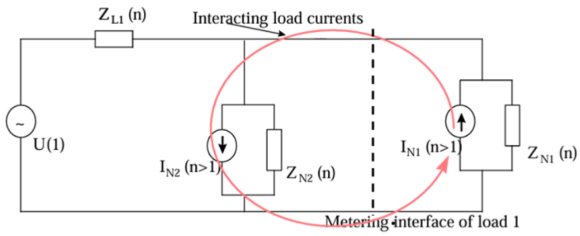
b) Load-source model, load 1 is studied, all other loads are lumped together into one extra load, and the system impedance divided into three parts. Normal case: *ZL3(n)>ZL2(n)>ZL1(n)*

Figure 1. Load-source models describing the metering of a non-linear load

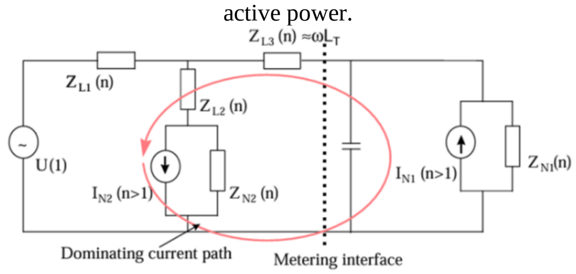
In Figure 2a, a nearby load generates current with an opposite sign, resulting in a high harmonic current level at the metering point. However, since this harmonic current is driven by both loads and does not pass through any significant impedance, the measured harmonic voltage and active harmonic power remain negligible. Additionally, the harmonic current flowing through the system impedance is also minimal, meaning that despite the high harmonic current at the metering point, it will not pose any issues for either the distributor or other loads.

On the other hand, if the load currents were of the same sign, the currents would likely add together, passing through the system impedance and generating higher active harmonic power in both the studied load and the nearby load. In this case, the harmonic voltage and active harmonic power would be significantly higher—approximately twice as much as if the metered load were the only nonlinear load in the area. Therefore, the active harmonic power generated by a nonlinear load is strongly influenced by both the system impedance and the presence of neighboring nonlinear loads [11].

Power measurement techniques for non-sinusoidal situations



a) Load-source model, loads electrically close, *ZL3(n), ZL2(n)<< ZL1(n)*, resulting in high harmonic current and (in this case) low harmonic voltage and low harmonic active power.



b) Load-source model, at transformer-compensator resonance conditions.

Figure 2. General load-system circuit diagrams for nonsinusoidal conditions showing the problems of the harmonic metering of a load for responsibility sharing purposes

Resonance risks, as shown in Figure 2b, further complicate the situation. The use of capacitors to compensate for fundamental reactive power typically reduces most harmonic voltage levels in the system by providing a low-impedance path for harmonic currents. However, in the event of resonance, the harmonic current and/or harmonic voltage levels can actually increase, particularly in localized areas. A power consumer with a significant motor load and compensating shunt capacitors might find themselves part of a resonance circuit driven by harmonic currents from another consumer. In this case, the consumer will experience high harmonic current and voltage levels, even if their load is not significantly nonlinear [12].

Typically, active harmonic power meters will indicate positive harmonic power in such scenarios. Much of the harmonic losses in the system will occur in the transformer closest to the load. Therefore, the amount of harmonic power measured will depend on where the metering is placed relative to the transformer. Another metering challenge arises with the third harmonic and other harmonics that exhibit a zero-sequence character, as they are usually trapped by the distribution transformer. As a result, the measured harmonic current will vary depending on whether the measurement is taken on the primary or secondary side of the transformer.

3. Conclusion

The conclusion is that while harmonic current meters can provide an indication of whether a load generates harmonics, they are unreliable for a full analysis. Active harmonic power metering, on the other hand, can help determine whether the harmonic current from a load is primarily caused by that load or if it is influenced by external factors. However, neither of these methods provides a complete picture of the behavior within the load or the broader power system.

The responsibility for harmonics can be approached in two ways. The first approach is to establish that the consumer's responsibility for current is always stricter than the distributor's responsibility for voltage. In this case, resonance or significant interaction would be considered the consumer's responsibility, and harmonic current could always be billed for or subject to limits (this could also be reversed, where a harmonic voltage above a set limit becomes the distributor's responsibility and cannot be billed to the consumer, requiring resolution by the distributor). While this is the simplest solution, it can sometimes be unfair, as illustrated earlier.

The second approach involves using a measurement method that distinguishes between imported and exported harmonic current problems. Ideally, this would involve a comprehensive load and system characterization. While accurate measurement of active harmonic power can differentiate between imported and exported harmonic currents, it cannot alone provide a complete characterization of the situation.

References

[1] Chica Leal A. J., Trujillo Rodríguez C. L., Santamaria F. Comparative of power calculation methods for single-phase systems under sinusoidal and non-sinusoidal operation //Energies. – 2020. – T. 13. – №. 17. – C. 4322.

[2] Siddikov I. K. et al. Statistical descriptions of multiphase current sensers of reactive power control systems in renewable power supply power systems //AIP Conference Proceedings. – AIP Publishing, 2023. – T. 2789. – №. 1.

[3] Abubakirov A., Kurbaniyazov T., Bekimbetov M. Analysis of three-phase asymmetrical currents in the secondary voltage of signal change sensors in the power supply system using graph models //E3S Web of Conferences. – EDP Sciences, 2024. – T. 525. – C. 03013.

[4] Kurbaniyazov, Timur Urunbayevich (2023) "Models of physical-technical effects in the processes of changing three-phase asymmetrical currents into a signal in the appearance of secondary voltage," Chemical Technology, Control and Management: Vol. 2023: Iss. 5, Article 7.

[5] Kurbaniyazov T. U., Bazarbaev A. B. Modeling the processes of conversion of asymmetrical three-phase currents into output voltage //TASHKENT STATE TRANSPORT UNIVERSITY ENGINEER. – 2024. – T. 2. – №. 4. – C. 2024.

[6] Abubakirov, A. B., Tanatarov, R. J., Kurbaniyazov, T. U., & Kuatova, S. B. (2021). Application of automatic control and electricity measurement system in traction power supply system. ACADEMICIA: An International Multidisciplinary Research Journal, 11(3), 180-186.

[7] Bazarbayevich A. A., Urunbayevich K. T., Pirnazarovich N. M. Reactive power and voltage parameters control in network system //innovative achievements in science 2022. – 2022. – T. 2. – №. 13. – C. 16-20.

[8] Blake J., Williams W., Glasov C., Bergh.R., Fetting K., Hadley E., and Sanders G., "Optical Current Transducers for High Voltage Applications", 2nd EPRI Optical Sensors Systems Vorkshop, Atlanta, Jan. 2000.

[9] Kh, Siddikov I. "Permissible Voltage Asymmetry for Asynchronous Motor Control in Non-Nominal Operating Situations." American Journal of Social and Humanitarian Research 3.9 (2022): 55-64.

[10] Kurbaniyazov, T. U. (2022). Distributed Active and Reactive Power Control With Smart Microgrid Demonstration. Middle European Scientific Bulletin,30,1-9.

[11] Siddikov I.Kh., Sattarov Kh.A., Khujamatov H.E. Research of the Influence of Nonlinear Primary Magnetization Curves of Magnetic Circuits of Electromagnetic Transducers of the Three-phases Current // Universal Journal of Electrical and Electronic Engineering. Horizon Research Publishing Corporation, USA. 2016, Vol.4(1), pp. 29 - 32, http://www.hrpub.org.

[12] Montoya F. G. et al. Analysis of power flow under non-sinusoidal conditions in the presence of harmonics and interharmonics using geometric algebra //International Journal of Electrical Power & Energy Systems. – 2019. – T. 111. – C. 486-492.

Information about the author

Kurbaniyazov Timur Urunbayevich	Nukus State Technical University, PhD., Acting Associate Professor of the Department of "Energy and Automation" E-mail: kurbaniazoff@gmail.com Tel.: +998913785200 https://orcid.org/0000-0001-5296-4600
Bazarbayev Abdulaziz Baqbergen ulı	Nukus State Technical University, Master's student of the specializing in "Technological Processes and Production Automation" E-mail: azizbazarbaev755@gmail.com Tel.: +998886510113 https://orcid.org/0009-0002-2617-9320

https://doi.org/10.56143/3030-3893-2025-2-44-47 A bridge between science and innovation

CONTEXT / MUNDARIJA

G. Ibragimova, Sh. Kayumov, M. Abduvaitova
Analysis of the transport sector and ensuring transport safety in the context of globalization ……………………………………………………………5

D. Mukimova
Study of the influence of roller disk thickness on the performance indicators of the device………………………………………………………………9

I. Karimov, I. Abduazimova
Determining the elasticity of the contact suspension of electrified railways……………………………………………………………………………12

J. Narimanov, N. Abdujabarov, D. Aliakbarov, K. Rakhimkariev
Maximizing efficiency in solar-powered UAVs: the role of MPPT algorithms in energy harvesting ………………………………………………16

N. Sulaymonov, D. Hakimov, K. Matrasulov
Improving organizational and technological mechanisms for the development of outsourcing services in transport logistics enterprises: Literature Review…………………………………………………20

A. Yangiboyev
The issues of using synthetic fuel in diesel transportation…………24

I. Maturazov, D. Sarsenbayev
Technology for improving the post-flight maintenance process of aircraft ……………………………………………………………………………28

S. Boltayev, E. Jonikulov, M. Khokimjonov, E. Khujamkulov
Analysis of the operating algorithm of switches in local control mode……………………………………………………………………………31

M. Sultonov, B. Akmuradov
The application of energy-saving technologies in parallel computing systems……………………………………………………………………………36

T. Kurbaniyazov, A. Bazarbayev
Analysis of measurement of harmonic power of non-sinusoidal currents in modern electrical networks……………………………………44