Keywords: Walsh functions, active power, reactive power.

Introduction: The measurement of the active and reactive electrical power (EP) is one of the important tasks in electric power industry especially in the electrical energy quality estimation and control. The reactive power (RP) influences directly to the power factor and plays a vital role in the stable operation of power systems [1].

The classic way to determine the RP includes its evaluation by using the measured values of the apparent power, \( S = UI \); and the active power, \( P = UI \cos \varphi \). Having the apparent power, \( S \) and the active power, \( P \), the RP, \( Q \) is found as \( Q = S^2 - P^2 \) or \( Q = UI \sin \varphi \). This way of RP measurement confirm the necessity of the measuring of the RMS values of voltage, \( U \) and current, \( I \), then a multiplication operation to obtain apparent power \( S \), therefore is complex due to the RMS values of \( U \) and \( I \), measuring of which is difficult.

In [2] the amplitude-pulse modulation together with phase shift operation is used to measure RP in the frequency range of from 50 to 70 Hz. An electronic shifter based on stochastic signal processing for digital implementation of a RP and energy meter proposed by authors in [3]. The authors in [4] suggest the computer algorithm for calculating RP. The approach of artificial neural networks to evaluate the instantaneous RP is described in [5]. In this method the back-propagation neural network is used to approximate the RP evaluation function. In [6] the digital infinite impulse response filters are used to measure the RP. Although proposed algorithm allows evaluate the harmonic components of the EP, the suggested method is still complex because the performing of the filtering procedures. A new application of the least error squares estimation algorithm for identifying the RP from available samples of voltage and current signals in the time domain for sinusoidal and non sinusoidal signals is suggested in [7].

In above analyzed scientific papers the known method of averaging of the value of the product of the current samples and the voltage samples with shifting to the quarter one of the samples (current or voltage) relatively to another is used. It is known that, phase shifting or time delay methods introduce errors [8]. The Fourier transform including fast Fourier transform based digital or analogue filtering algorithms used to measure RP, involve quite complex computations. The authors in [9] have analysed Walsh transform algorithms employed to energy measurement process and shown that the Walsh method represents its intrinsic high-level accuracy due to coefficient characteristics in energy staircase representation.

Proposed Method: In single-phase circuits with pure sinusoidal voltage and current signals an instant EP in discrete form can be written as:

\[
P(n) = P - \left[ P \cos \left( \frac{4\pi}{N} \cdot n \right) + Q \sin \left( \frac{4\pi}{N} \cdot n \right) \right].
\]

An analytical expression for the electric power by use of Walsh functions is

\[
S(i) = \frac{1}{N} \sum_{n=0}^{N-1} P(n)(-1)^{i-1} \sum_{k=0}^{m} (\omega_{m-k+1} \oplus \beta_{m-k}) \beta_k.
\]

Where \( i \) is serial number of the Walsh function and \( m \) is the binary representation of the highest-order Walsh function(in our case \( m=6 \)), \( \omega_m \) and \( \beta_k \) are the bit(digit) coefficients of the binary representations of the quantities of \( \omega \) and \( \beta \), respectively [10,11]. The zero-order Walsh function, \( \text{Wal}(0,t) \) equals to the one for the full normalized period of \( (0,N-1) \) [10,12]:

\[
\text{Wal}(0,t) = (-1)^{i-1} \sum_{k=0}^{6} (\omega_{k+1} \oplus \beta_k) \beta_k = (-1)^{i-1} = 1.
\]

So for the zero-order component of the electric power the \( S(0) \) is proportional to the average(active) value of the EP:

\[
S(0) = \frac{1}{N} \sum_{n=0}^{N-1} P(n)
\]
The third-order Walsh function is
\[ \text{Wal}(3, t) = (-1)^{\beta_2} \]
which allows us to find the average RP, \( Q_{\text{aver}} \):
\[
S(3) = \frac{1}{N} \sum_{n=0}^{N-1} \left\{ P \left[ P \cos \left( \frac{4\pi}{N} n \right) + Q \sin \left( \frac{4\pi}{N} n \right) \right] \right\} (-1)^{\beta_2} =
\frac{1}{N} \sum_{n=0}^{N-1} Q \sin \left( \frac{4\pi}{N} n \right) (-1)^{\beta_2} = Q_{\text{aver}},
\]
where \((-1)^{\beta_2}\) is defined as \([11]\) (See also Fig.1):
\[
(-1)^{\beta_2} =
\begin{cases} 
+1, \text{in the interval}\ [0, N/4] \text{ and } [N/2, 3N/4]; \\
-1, \text{at the intervals}\ [N/4, N/2] \text{ and } [3N/4, N-1].
\end{cases}
\]

Results: To examine the validity and effectiveness of the suggested Walsh transformation based method for evaluation of the active and the reactive components of the EP the simulation tool have been developed by use of “Matlab 6.5” software\([13]\). During experimental studies the phase shift, \( \varphi \) between the voltage, \( u(t) \) and the current, \( i(t) \) signals has been varied in the interval of from \( 0^\circ \) to \( 90^\circ \). The signal proportional to the instant value of the power \( p(t) \) is written as, (Fig.2):
\[ p(t) = 8 \sin(314t) \ast \sin(314t - \varphi). \]
The zero-, \( \text{Wal}(0, \beta_k) \) and the third-order, \( \text{Wal}(3, \beta_k) \) Walsh generators had next parameters: code length=16; code index=0; sample time \((1/50)16\) and code length=16; code index=3; sample time \((1/50)16\), respectively. The time representation of the signals
\[ S_0(t) = \text{Wal}(0, \beta_k) 8 \sin(314t) \sin(314t - \varphi) \]
and
\[ S_3(t) = \text{Wal}(3, \beta_k) 8 \sin(314t) \sin(314t - \varphi) \]
are shown in the Fig.2.

![Fig.1. Graphical interpretation of the RP measuring method](image)
The essential advantages of the proposed method for the measuring of the RP have been verified by experimental studies:

a) in contrast to the most of the known existing methods the proposed method does not require the neither analogue nor discrete time delay of the current/voltage signal to the $\pi/2$ (quarter) with respect to the voltage/current signal represented in either analogue or discrete form.

b) the measurement of the EP components with application of a Walsh function, introduced by a system of Rademacher functions, simplifies the volume of computing operations on some order in comparison with sets of algorithms based on decomposition of signals on harmonics (trigonometric components).

c) during digital signal processing the multiplication operation of the signals’ sample values by Walsh functions is replaced by summing of the samples with the corresponding $+1$ or $-1$ sign.

The simulation results have proved that the absolute error appearing because of the change of the phase shift, $\varphi$ in the interval of from 0 to $90^\circ$ does not exceed 0.015 VAR.

REFERENCES


