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Simulation of Frequency Spectrum of Electric Power Signal

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Introduction

Getting the phase information and the usage necessity of this phase information for many control systems in the power networks such as Pulse Width Modulation (PWM) rectifiers, active power filters, uninterruptible power supplies (UPS), active-reactive power controller have expanded the studies in this topic [1]. In some studies, the feasibility of getting the phase information by using digital signal processors and usability of this information at the control systems was proven by a simulation study [2].

Adaptable algorithms used in the identification methods are classified into two groups. First group is based on the least averages square algorithms. The least averages square algorithm minimizes the square average of the system error by a reduction search algorithm and it is very popular owing to the less calculation complication. But, convergence ratio of the least averages square algorithms is dependent on the system and the input statistics. Low convergence ratio of the system parameter estimation does not always result in satisfactory solutions. The second group is based on RLSM algorithm which minimizes the deterministic sum of error square.

The least squares (LS) approach has wide-spread applications in many fields, such as statistics, numerical analysis, and engineering. Its greatest progress in the 20th century was the development of the recursive least squares (RLS) algorithm, which has made the LS method one of the few most important and widely used approaches for real-time applications in such areas as signal and data processing, communications and control systems. Considerable efforts and significant achievements have been made in developing even more efficient RLS algorithms. The recursive least-squares, has long been employed as a simple alternative to Kalman filtering (KF) for tracking time-varying parameters [3]. KF as an estimator is well known to be optimal under the state-space model (SSM) assumption. One of the shortcomings of KF is the requirement of complete prior knowledge of the SSM and its parameters. Although under certain conditions the SSM parameters can be estimated from a set of observations via, for example, the Gaussian maximum likelihood approach, the problem of identifiably and numerical computation is not very easy to solve in general. It is also not always easy to validate the SSM assumption based solely on the observations. RLS on the other hand does not require a dynamic model for the time-varying parameters except for a forgetting factor. This, coupled with lower computational costs, makes RLS an attractive alternative to KF.

Su et all. investigated the performance limitation of a linear time invariant multivariable system in tracking a reference signal which is a linear combination of a step signal and several sinusoids with different frequencies [4]. Malik and Salman presented an adaptive algorithm to track a sinusoid signal buried in additive noise using state-space recursive least squares [5]. Zhang et all. addressed the problem of adaptive tracking the amplitude and phase of a noisy sinusoid by using recursive Gauss-Newton approach [6]. Synchrophasor measurements are applied in power systems to track dynamic conditions. In 2008, Premerlani et all. developed a synchrophasor estimator based on a complex Taylor expansion [7].

In this study, it is aimed to get phase information of the electrical voltage signal which has zero magnitude for a specific time interval by using forgetting factor approach of RLSE method. And also examination of the frequency spectrum with RLSM method algorithm is done. It is dwelled on locking period of the tracked signal using the phase information to be obtained. An interface was created at MATLAB for the forgetting factor approach of RLSE method.

Derivation of Forgetting Factor Approach from RLSM Method

A system with an output of $\{y(t)\}$ is assumed to be modeled by linear difference equations,

$$y(t) = a_1y(t\text{-}1)+a_2y(t\text{-}2)+...+a_ny(t\text{-}n)+v(t), \quad (1)$$

where, $v(t)$ is the white noise period; $t = 1,2,...,n$ is the instant time points. The equation (1) including delay operator can be written as,

$$q^{-1}y(t) = y(t\text{-}1), \quad (2)$$

$$A(q^{-1})y(t) = v(t). \quad (3)$$

In equation (3) delay operator as column vector $A(q^{-1})$ is

$$A(q^{-1}) = 1+a_1q^{-1}+...+a_nq^{-n}\ , \quad (4)$$

where, n is the degree and $a_1,....,a_n$ are unknown parameters of the model. If,

$$\theta^T = (a_1,...,a_n) \quad (5)$$

and

$$\varphi^T(t) = (-y(t\text{-}1),...,-y(t\text{-}n)), \quad (6)$$

then output becomes,

$$y(t) = \theta^T\ \varphi(t) + v(t). \quad (7)$$

The cost function can be defined by using the given model in equation (6) as,

$$V_n(\theta)=\frac{1}{n}\sum_{i=1}^{n}\beta(n,t)[y(t)-\theta^T\varphi(t)]^2\ ;t=1,2,\ldots \quad (8)$$

To estimate the parameters of the model, partial derivative of (8) is taken. Finally, LSM estimator is obtained as

$$\hat{\theta}(n)=\left(\sum_{i=1}^{n}\beta(n,t)\phi(t)\phi^T(t)\right)^{-1}\left(\sum_{i=1}^{n}\beta(n,t)\phi(t)y(t)\right), \quad (9)$$

where

$$\beta(t,k) = \prod_{j=k+1}^{t}\lambda(j)\ , \quad \beta(k,k) = 1. \quad (10)$$

The current information would contain much more information comparing to the previous one.

If, for each k, $\lambda(k)\leq 1$ and $\lambda(k)\leq k$ are taken, then from the equation (10)

$$\beta(t,k) = \lambda^{t-k} \quad (11)$$

is obtained. If the equation (11) is used in cost function $V_n(\theta)$ then it is assumed that the effect of new information is much more over cost function. Namely, it can be considered as if the old information is being forgotten. Therefore λ is called forgetting factor. Details about the other mathematical processes are given in [8, 9].

Implementation of Locking Algorithm into Electrical Voltage Signal

It is aimed to be locked on into single-phase signal and to adapt any possible changes of the signal by locking algorithm into single-phase signal by using RLSM method. The phase voltage for single-phase systems can be formulated as

$$E(t)=\overline{E}\ cos(\omega t+\phi)=\overline{E}\ (cos\phi\ cos\omega t\text{–}sin\phi\ sin\omega t), \quad (12)$$

where $\overline{E}$ is the maximum value of the voltage, ω is the radial frequency; ϕ is the phase angle. The phase voltage (15) can be obtained by reorganizing the equation (12) as follows:

$$E_d = \overline{E}\ cos\phi\ , \quad (13)$$

$$E_q = \overline{E}\ sin\phi\ , \quad (14)$$

$$E(t) = E_d\ cos\omega t - E_q\ sin\omega t. \quad (15)$$

For constant, $\overline{E}$, ω, E_d and E_q are constants in the state space. If we implicate the expression in (6) as

$$\varphi^T(t) = (\ cos(\omega t)\ \ -sin(\omega t)),\ \theta(t) = (Ed(t)\ \ Eq(t))^T \quad (16)$$

then, single-phase voltage will be

$$y(t) = \varphi^T(t)\,\theta(t). \quad (17)$$

Consequently, the study is constructed on the basis of algorithm (equations 18-21) derived from RLSM method.

$$\hat{\theta}(t) = \theta(t)+ K(t)(\ y(t) - \varphi^T(t)\,\hat{\theta}(t\text{-}1)), \quad (18)$$

$$r(t) = 1 + \varphi^T(t)P(t\text{-}1)\varphi(t), \quad (19)$$

$$K(t) = P(t\text{-}1)\varphi(t)r(t)^{-1}, \quad (20)$$

$$P(t) = \lambda^{-1}P(t\text{-}1) - \lambda^{-1}K(t)\varphi^T(t)P(t\text{-}1), \quad (21)$$

where $x(t\text{-}1) = 0$ and $P(t\text{-}1) = \pi_0\cdot I$. π_0 are the positive initial values. In the algorithm the phase angle is calculated by using equation (22).

$$\phi(t) = atan2\ (E_q\ (t), E_d\ (t)). \quad (22)$$

The calculation speed of phase angle changes that may possibly occur in the voltage is to be increased. In this study, covariance resetting technique is also added in order to increase the calculation speed of RLSM algorithm. Gain K is increased to a specific point by resetting P with a high value. When a sudden change occurs in the amplitude of the voltage or phase angle, this can be distinguished from the ordinary state by calculating the error value. If the calculated error is higher than the previously determined one, then P is reset by $\pi_0\cdot I$ which is the initial covariance value. Previously determined error value is 40%-20% of the nominal voltage's peak value [1]. Further for high values of λ that will be selected, the noise resistance of the calculation can be increased in this method.

Examination of Algorithm Response for Signal with Zero Magnitude for a Specific Time interval

Here, the algorithm response for the signal whose value is zero for a specific time period and then starts to increase again form a specific value with a different phase angle was examined. It is assumed that the signal started to increase from zero value at t=0 and at t=0,015 the value of the signal is zero. From this point, the algorithm uses the angle which is the one before the signal value became zero, as a sinusoidal form that will be run at the background. After the signal became zero, it was assumed that the sinusoidal_signal which is run at the background produced an output and it started again with a different phase angle at t=0,041.

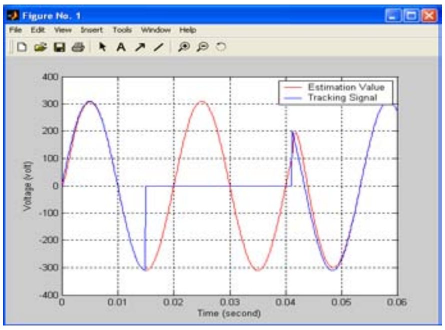

Fig. 1. Response algorithm for forgetting factor value, λ =0,95

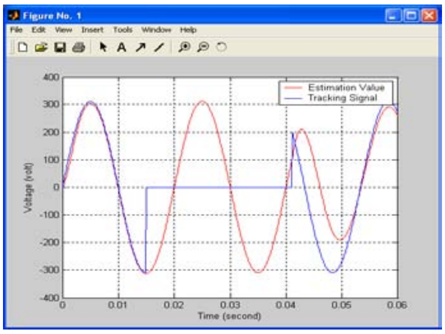

Fig. 2. Response algorithm for forgetting factor value, λ =0,99

The algorithm response for the state explained above was examined in Fig. 1 and Fig. 2. In this examination, the response curves of the RLSM's forgetting factor approach for λ=0,90 and λ=0,99 were graphed. As can be seen from the response curves, the sinusoidal form which is run at the background was used as an output after time, t=0,015 when the tracked signal value for approach is zero. The sinusoidal form which is run at the background uses the phase angle value at the moment of signal cutoff. Therefore, the tracked signal and the sinusoidal form which is run at the background were able to follow each other perfectly. Beginning from t=0,041, when the signal value started to increase with a different phase angle, the algorithm tries to adapt the signal into the signal whose sinusoidal form is run at background.

The signal change defines a suitable condition for the use of UPS. In this approach, when the network voltage cut off, the load can be feed from a DC source with the information that will be obtained from the sinusoidal form running at the background. After the network voltage is back and the locking is provided again, the load can be transferred to the network again.

The Examination of Frequency Spectrum with RLSM Method Algorithm

The frequency analysis of RLSM Method's forgetting factor approaches, with the phase angle shift at the tracked signal and the signal of the voltage collapse cases was emphasized. At t=0,025, a phase shift of 60and a voltage collapse of 30 V were created. The used signal sample includes 15% of 3rd degree, 8% of 5th degree and 7% of 7th degree harmonics. In the view of these circumstances, together with the phase angle change curves, the frequency spectrum curves of both tracked and calculated signal were graphed. The frequency spectrum was affected by the changes in value was examined by graphing the curves for different values of the forgetting factor that has a distinctive effect over the response of the algorithms of RLSM. For the investigation the frequency spectrum will be simulated for various values of the forgetting factors. The frequency spectrum curves of the tracked signal and its calculated value for different values of λ such as 0,90 and 0,99 in the forgetting factor approach are shown in Fig. 3 and 4.

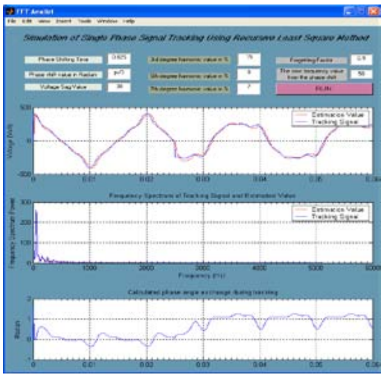

Fig. 3. Output of the software for λ =0,90

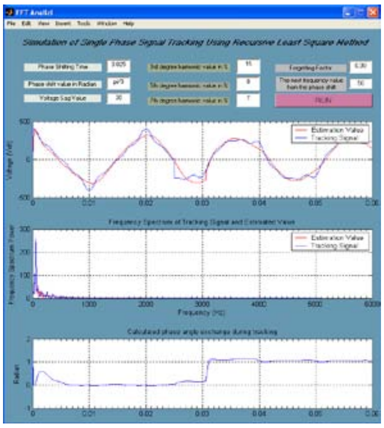

Fig. 4. Tracked signal and its calculated value for λ =0,99 together with the phase angle change

As could be seen from the outputs of the software, the frequency spectrum of the calculated signal for the small values of the forgetting factor is approaching to the spectrum of the tracked signal. The frequency spectrum of the calculated signal for the closer values of the forgetting factor to 1 is aparting from the frequency spectrum of the tracked signal. When the program outputs of approaching to 1 values of the forgetting factor was examined, it was observed that the power of 3rd, 5th and 7th harmonics was reduced. Considering this effect of the forgetting factor over the frequency spectrum depending on the application area, the forgetting factor value required to be selected by the user.

Conclusions

The states of the network voltage were simulated according to the forgetting factor approaches of RLSM Method. The sinusoidal form which is run at the background was used as an output after time, t=0,015 when the tracked signal value of the voltage signal is zero. The sinusoidal form which is run at the background uses the phase angle value at the moment of signal cutoff. Beginning from t=0.041, when the signal value started to increase with a different phase angle, the algorithm tried to adapt the signal into the signal whose sinusoidal form running at background was followed. The frequency spectrum of the calculated signal for the small values of the forgetting factor is approaching to the spectrum of the tracked signal. The frequency spectrum of the calculated signal for the approaching values of the forgetting factor to 1, is aparting from the frequency spectrum of the tracked signal. When the software results of approaching to 1 values of the forgetting factor was examined, it was observed that the power of 3rd, 5th and 7th harmonics was reduced.

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In this paper, recursive least squares method (RLSM) which is one of the adaptable classical methods is used. Forgetting factor approach is adapted to RLSM to obtain phase information of voltage signal belonging to an electric power network at first. Then responses of the algorithm are investigated for the signal which has zero magnitude for a specific time interval. And the examination of the frequency spectrum with RLSM method algorithm is done. Simulations are carried out by developing MATLAB^{TM} codes. Simulation results of method are presented. Ill. 4, bibl. 9 (in English; abstracts in English, Russian and Lithuanian).

Х. Х. Саиан, М. Кахраман, И. Косалай. Моделирование спектра сигнала электрической мощности // Электроника и электротехника. – Каунас: Технология, 2010. – № 4(100). – С. 21–24.

На основе применения метода наименьших квадратов дан анализ влияния формы сигналов управления. Для моделирования применена программа MATLAB. Приведены теоретические и экспериментальные результаты. Ил. 4, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

H. H. Sayan, M. Kahraman, İ. Koşalay. Elektros galios signalų dažnių spektro modeliavimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2010. – Nr. 4(100). – P. 21–24.

Analizuojamas klasikinis plačiai taikomas mažiausiųjų kvadratų metodas, pagrįstas užmaršties principu, siekiant gauti įtampos signalo fazės informaciją iš elektrinės galios tinklo. Gauti ir ištirti signalo atsakai, kurie tam tikrais laiko momentais yra lygūs nuliui. Atlikus dažnio spektro tyrimą mažiausiųjų kvadratų metodu, modeliuojama naudojant programų paketo MATLAB kodus. Pateikti modeliavimo rezultatai. Il. 4, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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