A NEW APPROACH FOR FREQUENCY ESTIMATION IN POWER SYSTEMS

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ABSTRACT: *This paper proposes a new method for correct and accurate signal estimation in electrical power system by Differential Evolution Algorithm. Frequency estimation modeled as an optimization problem using Data Window for sampling. The samples investigated with Genetic Algorithm and Differential Evolution Algorithm to estimate best sinusoidal waveform fitness. The procedure implemented in Matlab software. Results show that Differential Evolution Algorithm has acceptable accuracy and good convergence time.*

Keywords: frequency estimation, electrical power system, Matlab software, intelligence based Algorithms

1. INTRODUCTION

Power system is composed of non-linear and frequency dependence elements. Frequency is an important parameter in the operation and control of equipment that uses digital technology. This parameter can be destroyed by some phenomena and significantly affect on performance of the power system elements. Smart power system, requires a set of advanced equipment, methods of measurement, communication and control systems to provide more accurate control and estimation that has direct effect on control of system and quality of produced power [1]. Among advanced technology of smart power networks, PMU is a relatively new partner for amplitude, phase and frequency estimation methods for buses of power system.

Increase in power quality encourages researchers to find new tools and methods for accurate and instantaneous frequency estimating, so different techniques developed for estimating the frequency that are comparing based on their estimated accuracy and speeds in various conditions.

Fundamental frequency is requiring for measuring electrical parameters. There are many techniques to solve frequency estimation problems. Frequency estimation based on Supervised Newton-Gauss Algorithm proposed in [2].

Newton-Gauss Algorithm and Discrete Fourier Transform Algorithm with zero-crossing method [3] are used for approximate calculation of the amplitude and frequency. This combined method has good accuracy and acceptable speed. However, the zero-crossing method is sensitive to switching transients [4], noise and harmonics [5]. This method is based on time domain and voltage samples of half cycle.

The authors in [4] presented a method based on Perony analysis for frequency. However, this method had good results in simulation tests and estimated modulation in presence of harmonics and amplitude modulation, but requires decomposing input signal by the sine and cosine filters into orthogonal components. Then complex Perony analysis applied in exponentially complex by filtered sine and cosine signals to estimate the fundamental frequency.

Authors in [6] proposed a method to estimate frequency and harmonics by using optimized Adaptive filter. Particle Swarm Optimization is used as an alternative to minimizing the current and voltage error signals.

Genetic Algorithm used in many cases to solve optimization problem in frequency estimation. In reference [7] frequency, GA estimates Amplitude and phase Angle in two different objective functions. In this work, frequency estimates accurately by the method that shows its superiority on other methods such as fast Fourier transform.

Authors in [8] developed previous method with aim to minimizing estimation error and Immunity to noise. This proposed method is done for Field-programmable Gate Array, but FPGA is still complicated and leads to delay in the works. In our paper, we propose a method for estimating frequency using Deferential Evolution algorithm.

2. PARAMETER ESTIMATION BY OPTIMIZATION ALGORITHMS

Many research areas have been affected by the behavior of biological phenomena and developed many population based Algorithms. In this paper, a new method is presented for solving the problem of estimating the signal parameters. However, it is not easy to find which optimization algorithm is the best method for solving optimization problems. Nevertheless, the main point is that some methods are evolving quickly and the others slowly. Therefore, we expressed our estimation problem as a constrained optimization problem, and then by using its simplified form in different algorithms, we will determine the most appropriate method.

Constrained optimization is based on non-linear optimization problems [9]; the aim is finding $X=[X_1,X_2,\dots,X_D]$ that $X \in R^D$ to minimizing f(x). X vector is in relating with *m* Inequality constraint ($g_i(x)\le 0$) and j=1,… , D that D is problem dimension. $X_i^{(L)} \le X_i \le X_i^{(U)}$ That $X_i^{(L)}$ and $X_i^{(U)}$ are lower and upper limitation, respectively. Then new generation G^{th} can be generate.

2.1 DIFFRENTIAL EVOLUTION ALGORITHM

Differential Evaluation Algorithm is one of the most recent population based stochastic evolutionary optimization techniques for minimizing non-linear functions [10]. It is powerful algorithm due to convergence characteristics and few control parameters. In addition, it is true to say it is an improved version of GA.

Like GA, first generation is initialized randomly and further generations can be create through the application of evolutionary operator until a stopping criteria is reached. The optimization process has four basic operations namely: Initialization, Mutation, Crossover and Selection.

The advantage of this algorithm is having a memory that keeps appropriate answer information on the current generation. Another advantage of this algorithm is related to its selection operator.

DE starts with the number of population (NP) of D-dimensional search variable vectors as:

$$x^i = (x_1^i, x_2^i, ..., x_D^i) \quad (1)$$

If the i[th] parameter of the given problem has its lower and upper bound as x_i^L and x_i^U , respectively, then we may initialize the i[th] component of population members as :

$$x_{i,j}(0) = x_i^L + rand(0,1)(x_i^U - x_i^L) \quad (2)$$

The follow steps are iterative until stopping criteria :

* Mutation: changes a gene of our candidate chromosomes to keep away from the local optima. It randomly selects a population and then selects a gene of this chromosome. Note that its important to chek that chromosome is feasible or not. The equation (3) shows its operation:

$$y^i(iter) = x^{r3}(iter) + \beta.(x^{r1}(iter) - x^{r2}(iter)) \quad (3)$$

Where r1, r2, r3 ϵ [1,NP] are three random and are unequally numbers.β is scaling factor and usually consider equal to 0.5.

* Crossover: by the crossover operation, new solution is created and be evaluated. New solution Z^i can be determined by composing x^i and y^i as follow equation:

$$z^i = \begin{cases} y^{i,j}(iter) \rightarrow if : u \le CR, or, j = k \\ x^{i,j}(iter) \rightarrow otherwise \end{cases} \quad (4)$$

k is a random number between [0, D]. Also, u is random number between [0, 1]. *j* is number of each variable of i[th] member of generation. *CR* is crossover constant between [0,1].

* Selection: If new solution is better than the current answer, the new one chooses instant of previous one as:

$$x^i(iter+1) = \begin{cases} z^i \rightarrow fit(x^i(iter)) \le fit(z^i(iter)) \\ x^i \rightarrow otherwise \end{cases} \quad (5)$$

Finally, the best solution determines as final output.

2.2 OBJECTIVE FUNCTION AND STUDY PROCEDURE

Frequency estimation for electrical power system can be formulated by sine model for voltage or current signal in optimization algorithm. Sliding window is used to analyze the electrical signals to determine the dynamics of the electrical power system.

Mathematically, the objective function can be expressed as the following equation:

$$C(n, A, f, \theta) = e(n) = \sum [u(n) - A\sin(2\pi ft + \theta)]^2 \quad (6)$$

Where, *e (n)* is error function and we want to minimum it. *u* is input signal, *t* is sampling interval and n is samples time index.

A is Amplitude (P.u) between (0, 1.1). *f* is Frequency (Hz) between (48, 52) and phase angle is in radian (θ) between (0, 6.3). A, f and θ must be determined.

Different random sine waves in all range of parameters are generated in first iteration and we are seeking the best estimation by using optimization. We assumed that a normalized power system signal have maximum ± 2 Hz changes from nominal value, the search space is presented in Table 1. Objective function c(n, A, f, θ) in equation (6) is sum of squared errors, So we have a global minimum.

TABLE 1. Changing limit for electrical signal parameters

parameter	Range	unit
A	[0,1.1]	P.u
F	[48,52]	Hz
θ	[0.6.3]	Rad

3. SIMULATION RESULTS

To illustrate the effectiveness of the proposed method, several simulations are considered using Matlab software. Required waveforms are generated by Simulink and sampled with a predetermined rate of Δt interval. The samples are used for calculating phasor voltage and frequency deviation from the nominal frequency. Pure sine waveforms with different frequencies and different peak values and different phase angles are used to test the algorithm. We used Data Window to capture our waveforms. Time Reference is placed in the beginning of the data window. 30 samples are considered in per data window. For simplicity, a fewer number of samples is sufficient. However, different number of samples is better to evaluating of performance of the algorithm.

Sampling is done in 50 Hz. Figure 1 shows example waveform in 50 Hz. in this figure, data window is started from n=56.

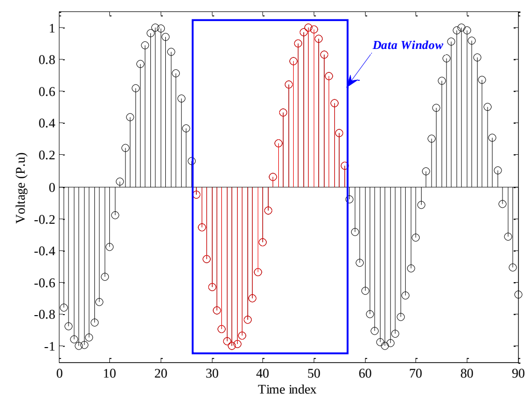


Figure 1. Data Window

Different evolutionary algorithms will examine various waveforms that are generated by described data windows.

Setting parameters of the algorithms are presented in table 2 and 3.

TABLE.2. GA Parameters

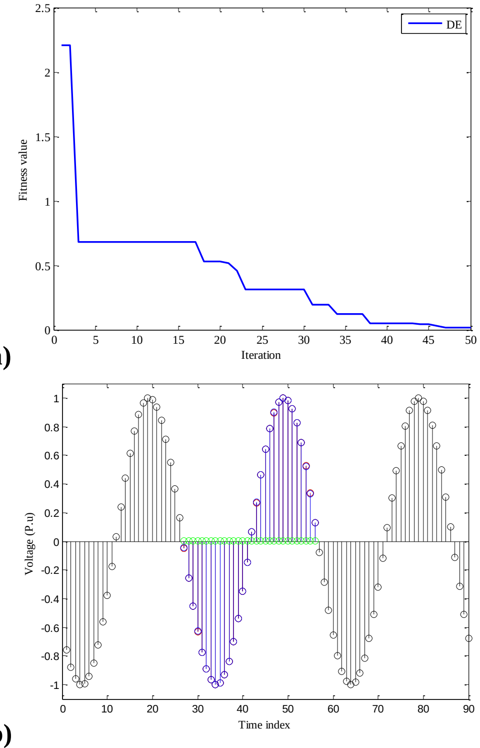
parameters	Value
Population size	50
Number of iteration	150
Selection	Stochastic uniform
Mutation function	Gaussian
Crossover	Single point

TABLE.3. DE Parameters

parameters	Value
Population size	50
Number of iteration	50
Crossover Probability	80%
Scaling factor	[0.2, 0.8]

3.1 Case 1

Consider the waveform with parameters: A = 1 Pu, f = 50 Hz and θ = 4 rad. Figure 2 shows convergence results, algorithms adaptation and the obtained responses compared with the original waveform.



(a)

(b)

Figure.2. DE algorithm convergence (a) and adaptation rate in first case study (b).

The green color represents the difference between the original waveform and sampled one. The simulation results for DE and GA are shown in Table 4.

TABLE.4. Results of the algorithms in the first study

parameter	Value	
	DE	GA
A	1.00014	1
f	50.0292	49.944
θ	3.99495	4.009
Error	0.003	0.034
Iteration	47	110

3.2 Case 2

If waveform parameters are A = 0.8 Pu, f = 49.8 Hz and θ = 4.2 radian, estimation results will be as shown in table 5.

TABLE.5. Results of the algorithms in the second study

parameter	value	
	DE	GA
A	0.799906	0.8
F	49.7944	49.725
θ	4.20088	4.214
Error	0.003296	0.037
Iteration	48	460

3.3 Case 3

In another study for waveform with parameters as A = 0.6 Pu, f = 49.4 Hz and θ = 4.6 rad estimation results are expressed in table 6.

TABLE .6. results of the algorithms in the third study

parameter	Value	
	DE	GA
A	0.600241	0.6
F	49.405	49.335
θ	4.1992	4.672
Error	0.004678	0.023
Iteration	45	380

Proposed method is tested for different cases. Comparison of the results is presented in table 7. It's clear that DE Algorithm with 0.28% error has minimum estimation error and GA has 1.94%. All results are obtained in less than 1 seconds and DE Algorithm has better response. Also, DE has well accurate and can be use in real time situation. Moreover, it's capable to use in real power system simulation.

TABLE.7. Summarized results

	Case 1	***Case 2***	***Case 3***	***Case 4***	***Case5***	**Mean Error**	**Mean error (%)**
A	**1**	**0.8**	**0.6**	**0.2**	**1.1**		
f	**50**	**49.8**	**49.4**	**49**	**51**		
θ	**4**	**4.2**	**4.6**	**5**	**2**		
Genetic Algorithm							
e	0.034	0.037	0.023	0.002	0.001	0.0194	**1.94**
It	110	460	380	220	150		
T	0.51 (s)	0.52 (s)	0.4 (s)	0.63 (s)	0.51 (s)		
Differential Evolution Algorithm							
e	0.003	0.003	0.004	0.0003	0.0031	0.0028	**0.28**
It	47	48	45	42	48		
T	0.4 (s)	0.42 (s)	0.4 (s)	0.38 (s)	0.42 (s)		

4. CONCLUSION

In this paper, the authors presented a new method to estimate frequency, amplitude and phase of power system signals. The approach uses the Differential Evolution algorithm and least mean square to minimize the difference between measurement and estimation. The method validated with several cases and the results show that DE has good performance in precision and speed and have ability to use in real time applications.

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