Voltage Flicker Parameters Estimation Using Shuffled Frog Leaping Algorithm and Imperialistic Competitive Algorithm

Saeid Jalilzade [1], Mehdi Mardani [2]
Department of Electrical Engineering, Zanjan University, Iran
Email: jalilzadeh@znu.ac.ir m_mardani@znu.ac.ir

ABSTRACT
Measurement of magnitude and frequency of the voltage flicker is very important for monitoring and controlling voltage flicker efficiently to improve the network power quality. This paper presents two new methods for measurement of flicker signal parameters using Shuffled Frog Leaping Algorithm (SFLA) and Imperialist Competitive Algorithm (ICA). This paper estimates fundamental voltage and flicker magnitudes and frequencies with proposed methods. The goal is to minimize the error of the estimated magnitudes and frequencies via a designed fitness function. At first, we introduce voltage flicker and its measuring techniques. Then voltage flicker model is analyzed. At the next part, a review of SFLA and ICA is presented. These methods will be applied to a test voltage signal and the results are be analyzed.

KEYWORDS: Voltage flicker signal, Flicker magnitude and frequency measurement, Shuffled Frog Leaping Algorithm (SFLA), Imperialist Competitive Algorithm (ICA).

1. INTRODUCTION

Voltage flicker is "the impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time". Voltage fluctuations are a systematic variations or a series of random changes in the voltage envelope. Cyclic flicker is repeatedly occurring over perhaps an extended period and is caused by periodic voltage fluctuations due to the operation of loads such as arc furnaces. Random changes in the voltage magnitude (non-cyclic flicker) refer to occasional voltage fluctuations due to operations such as the starting of large motors. Exhaustion of human eyes, malfunction of electronic controllers and protection devices, reduction the life span of the electronic, incandescent, and cathode ray tubes are in the result of voltage flicker. Thus, it is necessary to measure voltage flicker parameters in the power grid and evaluate them for designing suitable control devices to eliminate voltage flicker. Up to now, many techniques have been presented for digital analysis of voltage flicker parameters. Some of these techniques are listed as follows:

1. Techniques based on fast Fourier transform (FFT) [1,2].

2. Kalman Filtering technique [3, 4]
3. Wavelet transforms technique [7, 8]
4. Least Absolute Value state estimation technique (LAV), [6]

The conventional techniques have some deficiencies. Main disadvantage of applying either FFT or FFT prune techniques is the assumption of stationary signals. The application of such algorithms on non-stationary signals may lead to in accurate results. Kalman filtering technique is a difficult method because of its large mathematical burden and needs to accurate adjustment for its parameters. The wavelet transform method involves computational complexity and it has difficult process of choosing the candidate wavelet. The main disadvantage of the LAV state estimation technique is the assumption of knowing the flicker frequency in advance, which is not a realistic assumption. Moreover, it has slow convergence, which makes this algorithm not attractive for on-line tracking and implementation.

This paper presents two new methods for measuring flicker signals magnitude and frequency. For this aim, the methods based on SFLA and ICA optimization techniques are used. The goal is to minimize the error in estimated parameters. The proposed methods are tested with a flicker signal and the ability of these methods to measure the flicker magnitude and frequency is verified. At the end, these two methods are compared.

2. VOLTAGE FLICKER MODEL

Mathematically, voltage flicker signal is shown as follows [2, 5]:

$$V(t) = \left[A_0 + \sum_{i=1}^{m} A_{fi}\cos\left(w_{fi}t + \varnothing_{fi}\right)\right]\cos(w_0 t + \varnothing_0) \quad (1)$$

Where $\mathrm{V(t)}$ is the instantaneous voltage magnitude at time t, A_0 is the fundamental voltage amplitude, w_0 the power frequency, $\varnothing_0$ the phase angle of fundamental voltage, A_{fi} the amplitude of voltage flicker, w_{fi} the frequency ofvoltage flicker, $\varnothing_{fi}$ the phase angle of voltage flicker and m is the number of flicker modes.

In Eq.(1), the power frequency (w_0) is known, the problem is to estimateA_0, A_{fi}, w_{fi}, $\varnothing_0$ and$\varnothing_{fi}$with proposed methods. In general, Eq. (1) is written as:

$$Z(t) = F(t, x) + e(t) \quad (2)$$

Where $Z(t)$ is the measurement N*1 matrix. This matrix is given by measurement of digital signal samples with a suitable sampling frequency.$F(t, x)$is the N*1 information matrix given by Eq. (1) and is the function of time $t$and unknown variables$x$. $e(t)$ is the N*1error matrix associated with the estimation of unknowns x. The error at each time step is calculated by:

$$e_i(t) = V_{i\,actual}(t) - V_{i\,calculated}(t) \quad (3)$$

$V_{i\,actual}(t)$is the measurement voltage at time t that is given by measurement instruments. $V_{i\,calculated}(t)$is the voltage that is calculated from Eq. (1) by estimating the unknowns x with SFLA and ICA algorithms. In the problem of estimating the voltage flicker parameters, unknowns x are fundamental voltage amplitude, flicker amplitude, frequency and phase angle. The goal is to minimize the error between actual voltage and calculated voltage (e_i) by accurately estimating the optimum value of unknowns of the voltage flicker equation.

3. A REVIEW OF SFLA AND ICA ALGORITHMS

3.1 SFLA algorithm [9]

A mimetic meta-heuristic called the shuffled frog-leaping algorithm (SFLA) has been developed for solving combinatorial optimization problems. The SFLA is a population-based cooperative search inspired by natural behavior of a group of frogs when seeking for the location that has the maximum amount of available food. The algorithm contains elements of local search and global information exchange. At first, an initial population of N frogs is created randomly. Then the frogs are sorted in a descending order according to their fitness. Then, the frogs divided into "m" memeplexes in such a way that the first frog goes to the first memeplex, the second frog goes to the second memeplex, the mth frog goes to the mth memeplex and the (m+1)th frog goes back to the first memeplex. This algorithm continues until Nth frog. The SFLA performs simultaneously an independent local search in each memeplex using a particle swarm optimization like method. Within each memeplex, the frogs with the best and worst fitness are identified. During each memeplex evolution, the worst frog leaps toward the best frog. The position of the worst frog in each memeplex is updated as follows:

$$D = r.(x_b - x_w) \tag{4}$$

$$x_w(new) = x_w + D, (|D| < D_{max}) \tag{5}$$

Where *"r"* is a random number between 0 and 1, x_b and x_w are position of the frogs with best and worst fitness respectively and D_{max} is the maximum allowed change of frog's position in one jump. After a defined number of memeplex evolution steps, the virtual frogs are shuffled and reorganized into new memeplexes. To provide the opportunity for random generation of improved information, random virtual frogs are generated and substituted in the population if the local search cannot find better solutions. The flowchart of SFLA is showed in figure (1).

3.2 ICA algorithm [10]

Imperialist competitive algorithm is an evolutionary algorithm for the optimization problems, which is inspired by imperialistic competition of the countries of the world. Like other evolutionary algorithms, ICA starts with an initial population (countries in the world). Some of the best countries in the population are selected to be the imperialists and the rest, forms the colonies of these imperialists. All the colonies are divided among the imperialists based on their power, which is inversely proportional to colonies costs. Afterwards these colonies start moving toward their relevant imperialist country by x units.$x$is a random variable with uniform (or any proper distribution). Thus, x is as follows:

$$x \sim U(0, \beta * d) \tag{6}$$

Where β is a number greater than 1 and d is the distance between colony and imperialist. The direction of the movement is the vector from colony to the imperialist. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We will model this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies. Then the imperialistic competition begins among all the empires.

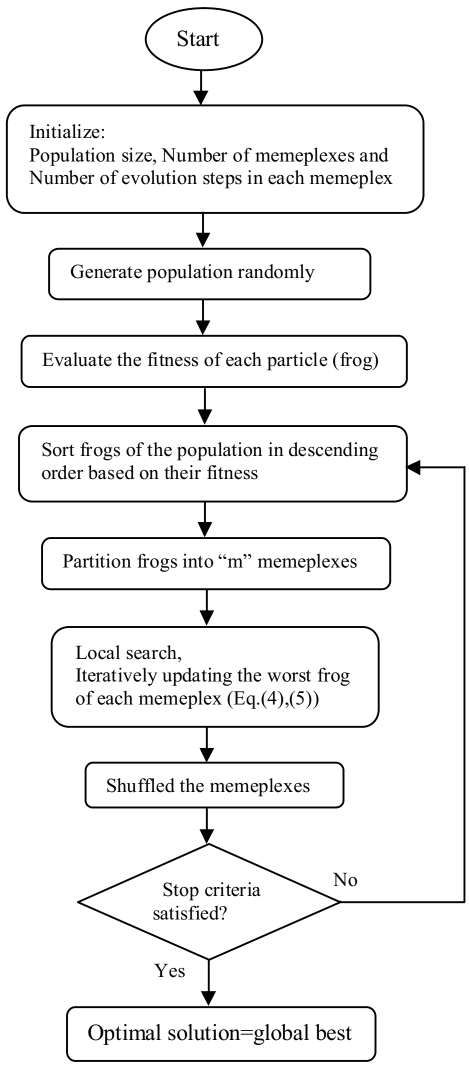

Fig.1. Flowchart of SFLA algorithm

Any empire that is not able to succeed in this competition and cannot increase its power (or at least prevent decreasing its power) will be eliminated from the competition. The imperialistic competition will gradually result in an increase in the power of powerful empires and a decrease in the power of weaker ones. Weak empires will lose their power and ultimately they will collapse. The movement of colonies toward their relevant imperialists along with competition among empires and the collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are colonies of that empire. In this ideal new world, colonies have the same position and power as the imperialist. The best country in this world is the optimum response. The flowchart of ICA is shown in figure (2).

Total cost of an empire computes as follows:

$$T.C._n = Cost(imperialist_n) + \zeta * mean\{Cost(colonies\ of\ empire_n)\} \quad (7)$$

Where $T.C._n$ is the total cost of n^{th} empire and ξ is a positive number which is considered to be less than 1. A little value for ξ causes the total power of the empire to be determined by just the imperialist and increasing it will increase the role of the colonies in determining the total power of an empire. In this paper, the value of 0.1 for ξ is used. We model imperialistic competition by just picking some (usually one) of the weakest colonies of the weakest empires and giving them (that) to an empire that have most chance to possess these (this) colonies. Based on their total power, in this competition, each of empires will have a chance to take possession of the mentioned colonies. To start the competition, first, we find the possession probability of each empire based on its total power. The normalized total cost is simply obtained by Eq. (8):

$$N.T.C_n = T.C_n - \max\{T.C_i\} \quad (8)$$

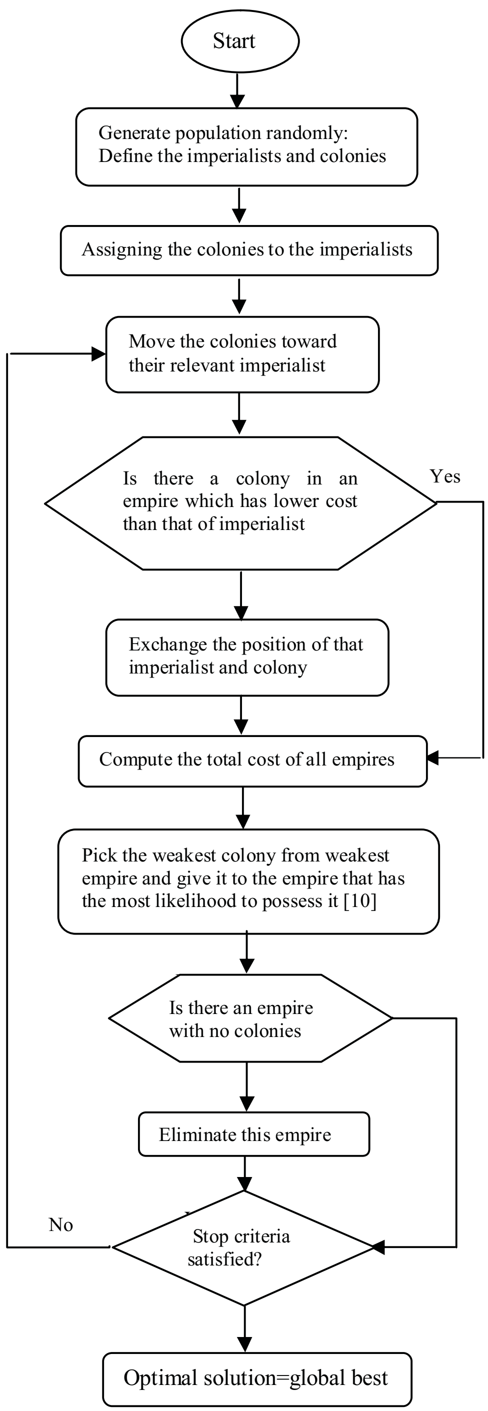

Fig.2. Flowchart of ICA algorithm

Where $T.C_n$ and $N.T.C_n$are respectively total cost andnormalized total cost of n[th] empire. The possession probability of each empire is given by:

$$p_{p_n} = \left| \frac{N.T.C_n}{\sum_{i=1}^{N_{imp}} N.T.C._i} \right| \quad (9)$$

To divide the mentioned colonies among empires based on the possession probability of them, we form the vector Pas follows:

$$P = \left[p_{p_1}, p_{p_2}, p_{p_3}, \dots, p_{p_{N_{imp}}}\right] \quad (10)$$

Then we create a vector with the same size as P whose elements are uniformly distributed random numbers.

$$R = \left[r_1, r_2, r_3, \dots, r_{N_{imp}}\right] \quad (11)$$

$$r_1, r_2, r_3, \dots, r_{N_{imp} \sim U(0,1)}$$

Then we have *D* vector as follows:

$$D = P - R = [D_1, D_2, D_3, \dots, D_{N_{imp}}] = \left[p_{p_1} - r_1, p_{p_2} - r_2, \dots, p_{p_{N_{imp}}} - r_{N_{imp}}\right] \quad (12)$$

The mentioned colonies will be given to an empire whose relevant index in *D* is maximum.

3.3 Fitness function

Fitness function is responsible for evaluation of the solution at each step.For reaching to the minimum error(e_i),we should consider a suitable fitness function for these optimization algorithms. The fitness function that is used in this paper is given in Eq.(8):

$$SS = \sqrt{\frac{\sum_{i=1}^{N} e_i(t)^2}{N}} \quad (13)$$

Where $e_i$is calculated by Eq. (3) and N is the number of samples. To reach to optimum estimates of flicker parameters, we should minimize SS with SFLA and ICA methods.

4. RESULTS

4.1 Case study one

We consider a sample voltage flicker model according to Eq. (14) to test proposed methods:

$$V(t) = [1 + 0.1\cos(2\pi 5t)]\cos(2\pi 50t) \quad (14)$$

Where $v_0(t) = 1 * \cos(2\pi 50t)$ is the carrier signal and$v_1(t) = 0.1 * \cos(2\pi 5t)\cos(2\pi 50t)$ is voltage flicker.

Table.1. Results of flicker parameters estimation with Shuffled Frog Leaping Algorithm (SFLA) and Imperialist Competitive Algorithm (ICA)

Optimization Algorithm	A_0	A_{f1}	w_{f1}	Run time (s)
SFLA	1	0.0999	5	63
ICA	1	0.1	5	7.1

The number of samples is 100 and sampling frequency is considered to be 150Hz. SFLA and ICA are applied to this sample voltage signal. The results are given in table (1).

4.2 Case study two

$$V(t) = [0.95 + 0.15\cos(2\pi 8.8t)]\cos(2\pi 50t) \quad (15)$$

The number of samples is 50 and sampling frequency is 200Hz. Proposed methods are applied to this sample voltage signal. The results are given in table (2):

Table.2. Results of flicker parameters estimation with Shuffled Frog Leaping Algorithm (SFLA) and Imperialist Competitive Algorithm (ICA)

Optimization Algorithm	A_0	A_{f1}	w_{f1}	Run time (s)
SFLA	0.95012	0.14899	8.8004	61
ICA	0.95	0.15	8.8	6.8

4.3 Discussion

As it is seen from tables (1) and (2), proposed methods estimates unknown parameters of voltage flicker with error less than 1%. With the same number of samples, Shuffled Frog Leaping Algorithm estimates fundamental voltage amplitude and flicker amplitude and frequency in about 6٠ seconds, but Imperialist Competitive Algorithm estimates those parameters in about 7 seconds. So Imperialist Competitive Algorithm convergence to the optimum parameters very faster than Shuffled Frog Leaping Algorithm.

These two optimization methods have excellent results for the flicker parameters estimation problem when the number of samples is more than 20 and sampling frequency is more than 100Hz. With increasing the number of samples and sampling frequency, SFLA and ICA gives best results for this problem.

Imperialist Competitive Algorithm results is better than Shuffled Frog Leaping Algorithm, as the flicker parameters estimation error in ICA technique is about zero (based on the number of samples and sampling frequency and the number of imperialists and colonies, it may have slightly error but it is less than 0.5%).

5. CONCLUSIONS

Two new methods for measurement of flicker signal parameters (magnitudes and frequencies) are proposed in this paper. These proposed approaches estimates fundamental voltage amplitude and flicker amplitude and frequency with high accuracy. The proposed algorithms are tested with two sample voltage flicker signals and the results are presented. In addition, these two methods are compared and the effect of the number of samples and sampling frequency has analyzed. The results verify high efficiency of Shuffled Frog Leaping Algorithm (SFLA) and Imperialist Competitive Algorithm (ICA) in estimating of voltage flicker parameters.

REFERENCES

[1] K.Srinivasan, “Digital measurement of voltage flicker” IEEE Transactions on Power Delivery, Vol. 6, No.4, pp. 1593-1598, Oct. 1991.

[2] M.T.Chen, “Digital Algorithms for Measurement of Voltage Flicker”, IEE Proceedings: Generation, Transmission and Distribution, Vol. 144, No. 2, pp.175-180, March.1997.

[3] C.S.Chen, H.J.Chuang, C.T.Hsu and S.M. Tseng, “Stochastic Voltage Flicker Analysis and its Mitigation for Steel Industrial Power Systems”, IEEE Porto Power Tech. Conference, Vol. 1, Porto, Portugal, Sept. 2001.

[4] P.K. Dash, A.K. Pradhan, G. Panda, “Frequency estimation of distorted power system signals using extended complex Kalman filter”, IEEE Transactions on Power Delivery, vol. 14, No. 3, pp. 761-766, July. 1999.

[5] S.A. Solaiman, M.E. El-Hawary, “Measurement of voltage flicker magnitude and frequency in a power system for power quality analysis”, Electrical Power Components and Systems, Vol. 27, No. 12, pp. 1289-1297, November. 1999.

[6] S.A. Soliman, G.S. Christensen, D.H. Kelly, K.M. EL-Naggar, “Least absolute value based on linear programming algorithm for measurement of power system frequency from a distorted bus voltage signal”, Electrical Power Components and Systems, Vol. 20, No. 6, pp.549-568, November. 1992.

[7] C. Ming-Tang, A.P. SakisMeliopoulos, “Wavelet-based algorithm for voltage flicker analysis”, IEEE Ninth International Conference on Harmonics and Quality of Power, Vol. 2, pp. 732-738, Oct. 2000.

[8] H. Shyh-Jier, L. Chen-Wen, “Enhancement of digital equivalent voltage flicker measurement via continuous wavelet transform”, IEEE Transactions on Power Delivery, vol. 19, No. 2, pp. 663-670, April. 2004.

[9] M. M. Eusuff, K. Lansey, F. Pasha,“Shuffled frog-leaping algorithm: a memetic meta-heuristic for discrete optimization,” ,Engineering Optimization, vol. 38, no. 2, pp.129–154, March. 2006.

[10] E. Atashpaz-Gargari, C. Lucas, “Imperialist competitive algorithm: An algorithm for optimization inspired by imperialistic competition”, IEEE Congress on Evolutionary Computation, pp. 4661-4667, CEC, Sep 2007.

[11] Wael M. AL-Hasawi, Khaled M. EL-Naggar “A Genetic Based Algorithm for Voltage Flicker Measurement”, Electric Power &

Energy Systems Journal, Vol.26, 2004, pp.593-596.

[12] A.K. Al-Othman, K. M. El-Nagger, “Voltage flicker measurement using particle swarm optimization technique for power quality assessment”, IEEE Electro-technical Conference, MELECON 2006pp. 1077-1082, May 2006.