Development of a Software for Computer-Aided Adjustment of Automatics for Elimination of Asynchronous Operation with Trapezoidal Characteristic

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Abstract*—Adjusting of automatics for elimination of asynchronous operation (AEAO) – a time-taking process associated with large manual-making operations, for which a computer-aided adjustment is critically. Satisfactory adjustment of AEAO supplied by carrying out multiple simulation operations in the course of processing source data (transition processes with asynchronous operations). The AEAO modeling and the computer-aided actuation characteristic adjustment – major processes, which are bases for developing software. Development is of the main computing units of the software based on methodological basis: instrumental guidance and recommendations of manufactures of AEAO, used in Russia united power grid. The software supports identify of including each points of the resistance vector hodograph to the actuation characteristic, determine the directional element and AEAO shape (taking into account restrictions in sensitivity), estimate time of location these hodograph points into AEAO characteristic (with the resistance descent speed) and represent results in graphical view. The software is used for AEAO run-in modeling and adjusting the one characteristic automatically. Emphasis in this process is not only calculation accuracy but also the rate of computing, as far as carrying out large multiple homogenous operations, for which executing (for adjusting AEAO characteristic) is need more computing time.

Keywords—automatic for elimination of asynchronous operation, AEAO, trapezoidal characteristic, software

I. Introduction

Automatics for elimination of asynchronous operation (AEAO) is a part of electric power system (EPS). AEAO is used for re-establishing of asynchronous operation in electric power transmission and for keeping of EPS susceptibility.

Satisfactory adjustment of AEAO supplied by carrying out multiple simulation operations of the transition processes with asynchronous operation (AO). The AEAO adjustment for the most part carry out in manual way. In this case, we lose more time. Development of a software for computer-aided adjustment of AEAO is the solution of this problem.

Computer-aided adjustment of AEAO reduces time spending by multiple calculations, which need for selecting the best possible the AEAO adjustment with meeting requirements of manufactures.

Now in software development process we use instrumental guidance and recommendations of manufactures of modern AEAO [1], broad-used in Russia united power grid.

II. Source Data

The problem of computer-aided adjustment of AEAO is that necessary to compute a characteristic (trapeze) with minimum size. AEAO with this characteristic must actuate by all AO sets [2].

Source data for developing software is values arrays of time *t*, active resistance *R* and reactive resistance *X*, which we generate in the course of transition processing with the use of the software “Eurostag” [3].

Every source data array include several tens of thousands of *t*, *R* and *X* values:

$$T_i = \{t_j\},\ M_{R,i} = \{R(t_j)\},\ M_{X,i} = \{X(t_j)\},$$

$$j = \overline{1,n},\ i = \overline{1,m},$$

where T_i – time values array, $M_{R,i}$ – active resistance values array, $M_{X,i}$ – reactive resistance values array *n* – amount of values in array, *m* – amount of data arrays.

Every source data array is a hodograph of one AO. For adequate actuation of AEAO, established in electric utilities, we must have regard to all AO sets for examining electric power transmission.

Key problem of the manufacture recommendations [1] is the description of AEAO adjustment only for one AO. This singularity is the bottleneck of the adjustment process, because that necessary to carry out large manual-making operations.

It should be note that we do not have fixed time step in arrays when calculate of transition processes. Concentration of hodograph points in arrays increases when we have the degradation of electrical power mode.

III. AEAO Actuation Principle

We shall consider in the principle of the AEAO actuation when the AO hodograph intersects the AEAO characteristic.

AEAO registers sequencing of the AO hodograph through the sensitive element (SE) (fig. 1, points №№ 1, 2) and the coarse element (CE) (fig. 1, point № 3) of the AEAO characteristic, intersecting the directional element (DE) and entering this hodograph in the second half of the characteristic CE (fig. 1, point № 4).

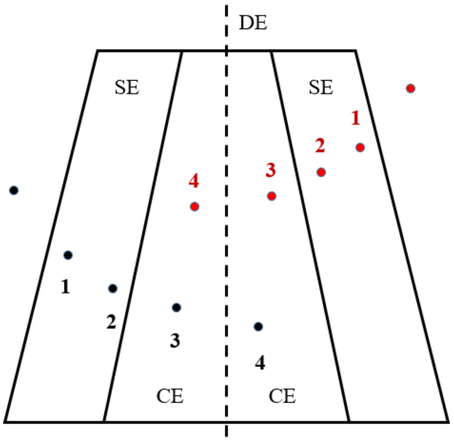

Fig. 1. AEAO actuation principle

If we keep this sequence (SE-CE-DE-CE) and the hodograph location time within characteristic SE $T_{SE} = t_2 - t_1$ (fig. 1, time difference between points № 2 and № 1) more of defined actuation time T_{act}, then AEAO cuts out a power equipment.

IV. DETERMINING OWNERSHIP OF HODOGRAPH POINTS TO THE GEOMETRICAL FIGURE

A. Comparison among Algorithms

Calculating the characteristic (trapeze) is multiple repeat of homogeneous operations. The bottleneck of hodograph processing is determining ownership of hodograph points to the AEAO characteristic.

Trapeze with no trouble shows up as two triangles. We examine the operation speed of computational algorithms: squares comparison method, coordinates relativeness method, vector method and ray tracing method.

Detailed descriptions of these methods with examples of program implementations on different languages with no trouble can be find in the Internet.

For measurements of processing times, we use the computer with processor Intel(R) Core(TM) i7-7700HQ CPU 2.80 GHz under the operating system Windows 10.

Amount of processing points is 10^{10}.

Table 1 shows results of calculations for different methods. The vector method gives the smallest time of problem solution. The worst result – squares comparison method.

TABLE I. RESULTS OF CALCULATIONS

Method	**Calculation Time, (s)**
Squares comparison method	923
Ray tracing method	609
Coordinates relativeness method	604
Vector method	410

Computational experiment shows that vector method is adequate for determining ownership of hodograph points to the triangle with accuracy of calculations only for three decimal places.

As the base of the software module for determining ownership of hodograph points to the AEAO characteristic we take coordinates relativeness method.

B. Speedup of Computations

Using of coordinates relativeness method for processing actual data sets claims the more computational resources. With this context, we modify coordinates relativeness method.

Determining ownership of hodograph points to the rectangle claims substantially smaller amount of calculations than coordinates relativeness method. Processing time for 10^{10} points is 127 s. For this reason, we combine these algorithms for reducing computational resources.

Principle of the combined method: the rectangle circumscribes the trapeze (see fig. 2, dashed rectangle with blue light); foremost for all points we determine ownership to the rectangle; if a point locates within circumscribing rectangle, we determine the ownership to the trapeze.

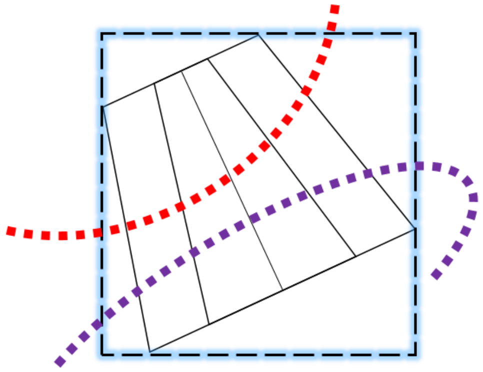

Fig. 2. Circumscribing rectangle

If amount of points, located within circumscribing rectangle, is 10 % of the total amount, then calculation time is about 30 %.

V. LOCATION OF DIRECTIONAL ELEMENT

Final shape of the AEAO characteristic is dependent on the DE location. Altitude of the trapeze lays on this DE.

A. Altitude of Trapeze (Characteristic)

The trapeze will be have the smallest size, if DE intersects the area with the largest concentration of points (fig. 3, within red rectangle).

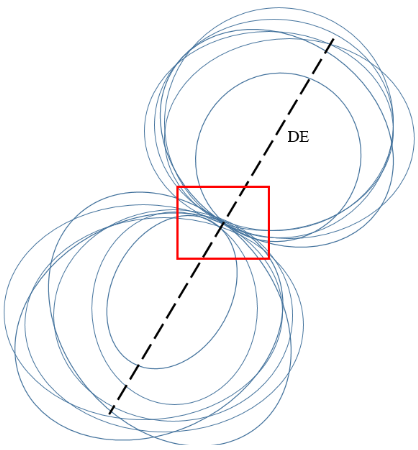

Fig. 3. Location of directional element

The center of the trapeze altitude is calculated as the mass center [2]. All hodograph points, located within red rectangle, are viewed as system elements. Every point has equal weight. For this points system we calculate equilibrium point *C*. The point *C* is the center of the trapeze altitude.

B. *Slope Angle of Directional Element*

Width of bases and height of the trapeze altitude are dependent on a slope angle of DE (see fig. 4).

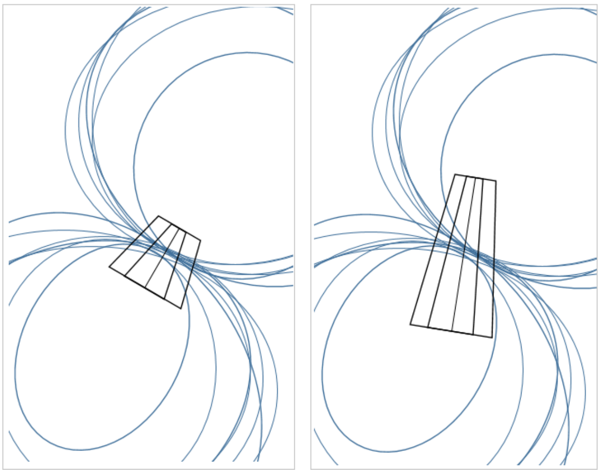

Fig. 4. Examples of final characteristic shape with difference in angle

As an initial slope angle, we use the slope angle α of the resistance vector of the power equipment, protected by AEAO.

For correcting the slope angle of DE, we use method, based on the principle of bisection method [2] (fig. 5).

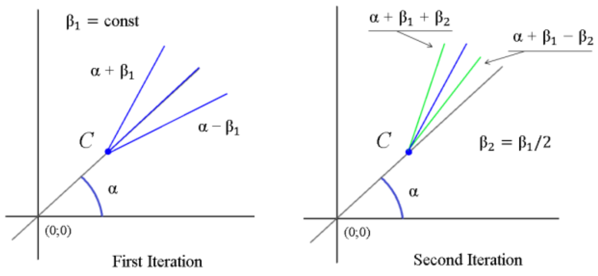

Fig. 5. Determining slope angle

Steps of the method:

1) Calcutate the AEAO characteristic with the slope angle α, $\alpha+\beta_1$, $\alpha-\beta_1$, where β_1 – constant of deviation from initial slope angle α.

2) Save the best result. As an example on fig. 5 the best result is $\alpha+\beta_1$.

3) Recalculate initial slope angle. The angle $\alpha+\beta_1$ is saved as the initial angle. We calculate a new angle of deviation $\beta_2=\beta_1/2$.

We repeat calculating the AEAO characteristic analogically to step № 1 with the slope angle $\alpha+\beta_1$, $\alpha+\beta_1+\beta_2$, $\alpha+\beta_1-\beta_2$ and choose the best result. Deviation angle β_i is reduced on the half, where i – number of the correction iteration.

We repeat all calculation steps until there is the result improvement.

Multiple calculations shows that correcting the slope angle of DE usually is stopped on the second iteration. In rare cases, the third iteration is required.

VI. Determining Trapeze Bases

Together with calculating the slope angle of DE, we determine sizes of trapeze bases. It is necessary to calculate bases with minimum size, which allow the actuation principle of AEAO: $T_{SE}>T_{act}$ (section III).

We put initial bases size such that the location time of every AO hodograph within left and right halves of the trapeze comes $t_2-t_1>2\cdot T_{act}$ (fig. 6).

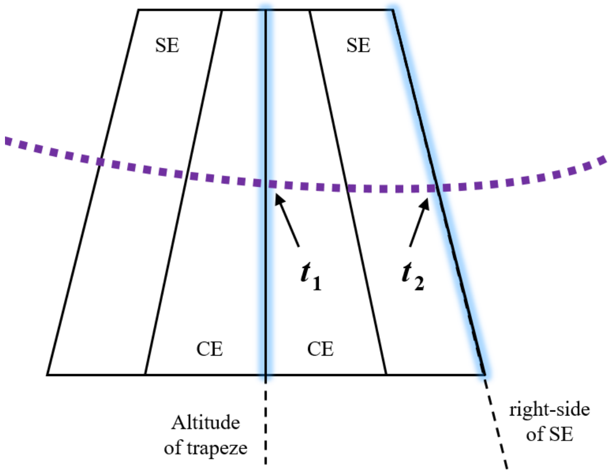

Fig. 6. Determining initial characteristic shape

After that, we form the trapeze and save figure symmetry and proportionality of SE and CE [1].

The actuation principle is checked for all AO hodographs. If AEAO do not register an AO hodograph ($t_3-t_2<T_{act}$), then trapeze bases are stretched (see fig. 7).

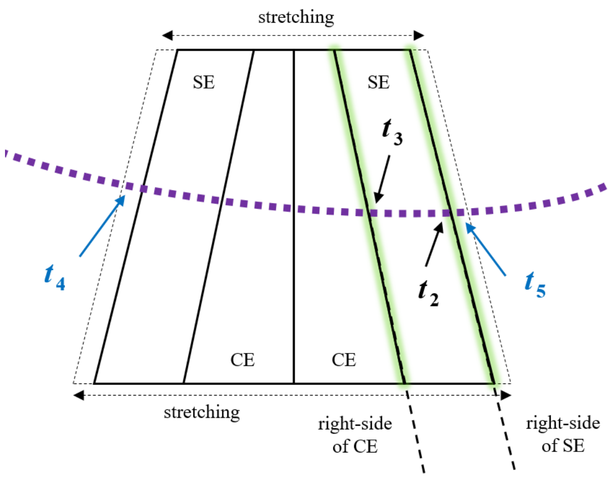

Fig. 7. Streching trapeze bases

We stretch trapeze bases so that to cover neighbor points (see fig. 7, points t_4 and t_5) of every AO hodograph, which are not registered by AEAO.

The whole sequence of corrections and checks is repeated, that to calculate the best possible AEAO characteristic, which allows registering all AO.

VII. SENSITIVITY CONSTRAINTS

Important feature of the AEAO adjustment is keeping of sensitivity constraints [1]. Such adjustment increases AEAO flexibility and automatics registers all potential AO, which not generated with the use of the software “Eurostag” [3] and not used as source data for calculating final characteristic shape.

All AO hodographs must intersect sides of SE, CE and the trapeze altitude with saving the special proportions [1]. For example for the left-side of SE (see fig. 8):

$$l_{LS\ SE,\,top} > 0.1 \cdot l_{LS\ SE}\,,$$

$$l_{LS\ SE,\,bot} > 0.1 \cdot l_{LS\ SE}\,,$$

where $l_{LS\ SE}$ – length of the left-side SE, $l_{LS\ SE,\,top}$ – length of the interval, bounded by the top trapeze base and the upper-crossed AO hodograph, $l_{LS\ SE,\,bot}$ – length of the interval, bounded by the bottom trapeze base and the down-crossed AO hodograph.

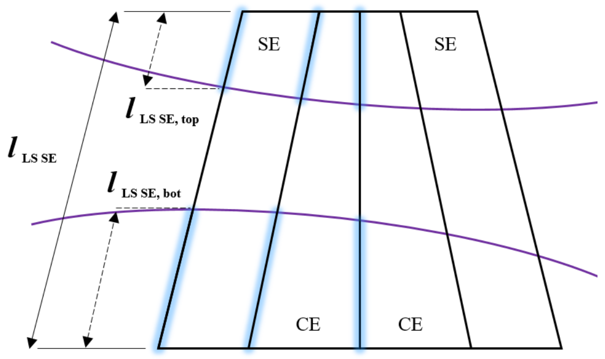

Fig. 8. Observance of sensitivity constraint

Analogical constraints need to keep for the left-side CE, the trapeze altitude, the right-side SE and CE.

It should be note that we must calculate the sides, the bases and the altitude of the trapeze with minimum size (section II).

VIII. DIRECTION OF HODOGRAPH ROTATION

Every AO hodograph rotates in a direction. Rotation direction of the AO hodograph has major importance for the action of AEAO.

If the AO hodograph has right-hand rotation (fig. 9, the line with blue light), then for AEAO is checked the right sequencing (right-side SE-CE-DE-CE). In this case the hodograph location time T_{SE} (within the left-side SE) is not determined and not used for calculating final characteristic shape.

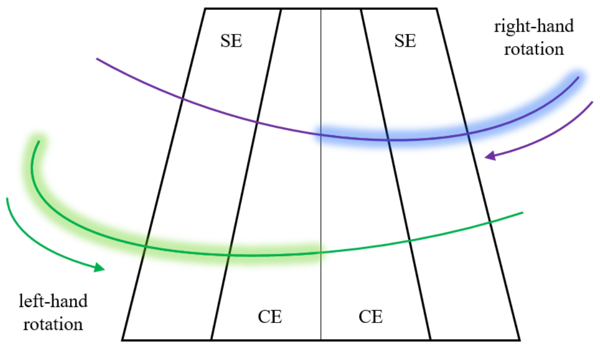

Fig. 9. Direction of hodograph rotation

Fig. 10 shows the result of the developing software action. Calculated AEAO characteristic (dark-green trapeze) registers all AO hodographs (blue lines). Purple arrow – the resistance vector of electric power lines, protected by AEAO. Light-green axis – DE of AEAO. *R* – active resistance. *X* – reactive resistance.

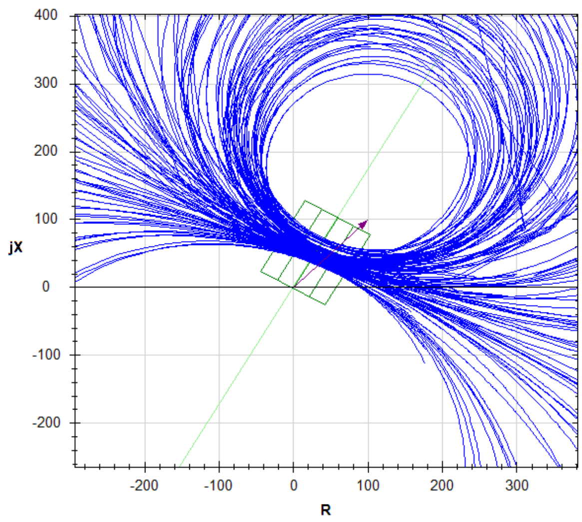

Fig. 10. Software output

Fig. 11 shows the AEAO characteristic and AO hodographs, filtered out by the rotation direction. AO hodographs are drawn in truncated version. We can see the first rotation cycle (the first intersection of the AEAO characteristic).

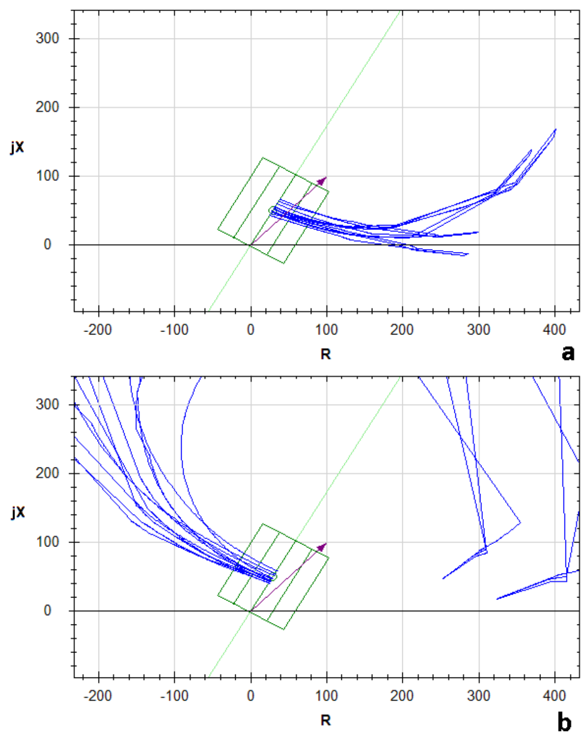

Fig. 11. Software output with different directions of rotation:
a – right-hand rotation; b – left-hand rotation.

It should be note that we keep all sensitivity constraints (section VII) for calculated AEAO characteristic: sides of SE, CE and the trapeze altitude are divided by AO hodographs with required proportions.

IX. Computational Software Modules

Now the software for computer-aided adjustment of AEAO is developed for automatics with trapezoidal characteristic [1] for the next modules:

- Determining ownership of hodograph points to the AEAO characteristic (section IV).
- Simulating the AEAO actuation (section III).
- Determining the DE location (section V).
- Calculating trapeze bases (section VI).
- Correcting the AEAO characteristic with sensitivity constraints (section VII).
- Determining direction of AO hodographs rotation (section VIII).

All modules are interdependent units of the software and everyone is used for calculating the AEAO characteristic (trapeze) in defined sequence.

Every module can be activated individually for computer-aided correction of some elements of the AEAO characteristic when we use manual-making mode in the software.

Graphical representation of the AEAO characteristic, DE, the resistance vector of the power equipment, AO hodographs (all together, by ones, internal/external AO, registered/non-registered AO) is implemented (see fig. 10, 11).

In addition to computer-aided adjustment of AEAO for registering the resistance changings, also we implement the module for registering current oscillations by AEAO, more details in [4].

X. Conclusion

Computer-aided adjustment of AEAO allows essentially cutting down the computing time and implements users by special tools for multiple-path calculations and selection of the best possible characteristics, meeting the manufactures requirements for AEAO.

The software is used for AEAO run-in modeling (simulating the AEAO actuation) and adjusting characteristic in automatic and manual way.

Emphasis in computer-aided adjustment process is not only calculation accuracy but also the rate of computing, as far as carrying out large multiple homogenous operations, for which executing (for characteristic AEAO adjusting) is need more computing time.

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