Developing of method for primary frequency control droop and deadband actual values estimation

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Abstract. Operation of thermal power plant generation equipment, which participates in standardized primary frequency control (SPFC), must meet specific requirements. These requirements are formalized as nine algorithmic criteria, which are used for automatic monitoring of power plant participation in SPFC. One of these criteria - primary frequency control droop and deadband actual values estimation is considered in detail in this report. Experience shows that existing estimation method sometimes doesn’t work properly. Author offers alternative method, which allows estimating droop and deadband actual values more accurately. This method was implemented as a software application.

Operation of thermal power plant generation equipment, which participates in standardized primary frequency control (SPFC), must meet specific requirements. These requirements are formalized as nine algorithmic criteria, which are used for automatic monitoring of power plant participation in SPFC [1]:

- Failure to provide information;
- Time step of data transmission doesn’t meet the requirements;
- Primary frequency control range doesn’t meet the requirements;
- Precision of data logging doesn’t meet the requirements;
- Automatic load frequency control system is in non-automatic mode;
- Load control precision doesn’t meet the requirements;
- Primary frequency control droop and deadband actual values don’t meet the requirements;
- Lack of response to frequency change;
- Oscillation.

These criteria are presented in the document ‘The procedure for determining the volume of SPCF services (Appendix 2. Criteria for monitoring of power plant participation in SPFC)’ of Joint-stock Company ‘System Operator of the United Power System’.

Primary frequency control droop and deadband actual values estimation is considered in detail in this report. Author offers a method, which allows estimating droop and deadband actual values accurately enough.
Primary frequency control deadband is a specified value of the frequency deviation from the nominal value, which does not require primary control. Primary frequency control deadband minimal value is equal to actual deadband of automatic load frequency control system.

Primary frequency control droop is a coefficient that determines changing of active power under the action of frequency control system at frequency changing.

At present droop and deadband actual values are estimated in monitoring using statistical methods of data processing. The droop and the deadband are determined as parameters of the frequency deviations $\Delta f$ and active power deviations $\Delta P$ regression function.

The use of the criterion for the operation of Karmanovskaya thermal power plant (TPP) unit 2 is shown in the figure 1.

![Figure 1](image-url)

**Figure 1.** The primary frequency control droop and deadband actual values estimation for the operation of Karmanovskaya TPP unit 2.

The droop and the deadband values are estimated ($S = 6\%$, $DB = 0.024$ Hz). But, as can be seen from the figure 1, the deadband estimate is not correct enough. Probably, this is due to the regression function smoothing and association to origin.

In this regard, consider an alternative method. Below are the steps in the alternative method algorithm.

From source variables $f, P_{act}, P_{pl}$, $P_{pl}$, where $f$ – frequency measurements array, $P_{act}$ – actual active power measurements array, $P_{pl}$ – planned active power, move to vectors of relative variables $x, y$:

$$x_i \equiv \Delta f_i = f_i - 50, \quad y_i \equiv \Delta P_i = \frac{P_{act,i} - P_{pl,i}}{P_{nom}} \cdot 100$$  \hspace{1cm} (1)

Here $P_{nom}$ – electrical power unit nominal power.
A 'cloud' of points \( x_i, y_i \) is drawn up.

The range from \( x_{\text{min}} \) to \( x_{\text{max}} \) is divided into \( N \) intervals.

The width of the interval should be no more than 1.5 mHz and the number of points in the interval must ensure the accuracy of the calculation. From these conditions, the number of intervals is taken.

At each interval, the average value of \( y \) is calculated:

\[
M_y = \frac{1}{m} \sum_{j=1}^{m} y_j
\]

where \( m \) – the number of points in the interval, \( N, j = 1 \ldots m \).

As a result we obtain two vectors \( x_{\text{av}}, y_{\text{av}} \) with \( N \) elements in each vector. Vector \( y_{\text{av}} \) contains \( M_y \) of each interval, vector \( x_{\text{av}} \) contains \( x \) values in the middle of each interval.

\( M_y \) graph is constructed in conjunction with a 'cloud' of points and the so-called 'theoretical' graph based on the specified values of deadband and droop (in most cases for equipment, which participates in SPFC, \( S = 5 \% \), \( DB = 0.02 \) Hz).

On the left and right of the graph, two auxiliary lines are constructed. One point for construction (with coordinates \([M[x_i];M[y_i]]\), where \( M \) is expectation function) is common for the left and right lines. The second points for construction are on the \( M_y \) graph. Near the boundaries of the range (\( x_{\text{min}} \) and \( x_{\text{max}} \)), the intervals contain few points, because of this there is a large spread of the mean values in these intervals. This can affect the accuracy of the deadband estimation. Therefore, it is necessary to locate each of the points at a distance of 14% of the range width (\( x_{\text{min}} \) to \( x_{\text{max}} \)) from the range boundaries. The value of 14% was obtained empirically. Thus, auxiliary lines \( y_{\text{aux}} = a_1 x + b_1 \) and \( y_{\text{aux}} = a_2 x + b_2 \) are constructed. Here:

\[
a_1 = (M[y] - y_{\text{av}}[o_1])/(M[x] - x_{\text{av}}[o_1]) \quad b_1 = M[y] - a_1 M[x] \\
a_2 = (M[y] - y_{\text{av}}[o_2])/(M[x] - x_{\text{av}}[o_2]) \quad b_2 = M[y] - a_2 M[x]
\]

Here: \( o_1 \) and \( o_2 \) are numbers of intervals located at a distance of 14% of the range width from the range boundaries.

Between \( o_1 \) and \( o_2 \) (on the left and right of the graph) on each interval the distance between the auxiliary line point and the \( M_y \) graph point is calculated. Two \( x_{\text{av}} \) values (on the left and right of the graph), for which the distances between the auxiliary line and the \( M_y \) graph are maximum, are estimated values of the boundary of the deadband.

For the left and right of the graph, three values of the droop are calculated. The mean value of the droop is calculated from them. Values of the droop are calculated by the formula:

\[
S = -200 \cdot \frac{x_1 - x_2}{y_1 - y_2}
\]

Here: \( x_1 \) and \( y_1 \) are values from vectors \( x_i, y_i \) for intervals located at distances of 3\%, 6\%, 10\% (for each droop value) of the range width from the range boundaries, \( x_2 \) and \( y_2 \) are values from vectors \( x_i, y_i \) for intervals located at a distance of 5\% of the range width from the deadband boundaries. The values of 3\%, 5\%, 6\%, 10\% were obtained empirically.

Based on the estimated values of droop and deadband, a piecewise linear graph of the "estimated" static characteristic can be constructed. An example is shown in the figure 2.
In the figure 2: green is the $M_y$ graph; red is the piecewise linear graph; s11, s21, s31, s12, s22, s32 are points located at a distance of 3%, 6%, 10% (for each droop value) of the range width from the range boundaries; s01, s02 are points located at a distance of 5% of the range width from the deadband boundaries; max1, max2 are maximum distances between the auxiliary line and the $M_y$ graph.

Thus, the algorithm allows to estimate the deadband and the droop separately for negative and positive frequency deviations. Often these deviations are asymmetric with respect to zero.

The algorithm flow chart is shown in the figure 3.
The transition to relative variables $x$ and $y$

The partition of range from $x_{\text{min}}$ to $x_{\text{max}}$ into $N$ intervals

The calculation of the mean value $M_y$ at each interval.
The formation of variables $x_{av}$, $y_{av}$.
The $M_y$ graph construction.

The auxiliary lines construction $y_{aux}=a_1x+b_1$ and $y_{aux}=a_2x+b_2$

Finding the maximum distances between the $M_y$ graph and the auxiliary lines for estimating the boundaries of the deadband

The drop estimation

End

Figure 3. The algorithm flow chart.

The described algorithm was implemented as a software application. The arrays $x$ and $y$ calculated from the source data must be inserted into the two fields of the application window. After that, you must click the ‘Get Arrays’ button and specify the values of $x_{\text{min}}$, $x_{\text{max}}$ and $N$. After clicking on the "Get Average" and "Inclined Line Method" buttons, the program calculates the values of the droop and the deadband and displays them on the screen. Using the "Graph" button, graphs are displayed.
Estimates of the actual values of the deadband and the droop obtained by different methods are shown in the figures 4 and 5.

![Figure 4](image1)

(a)

![Figure 5](image2)

(b)

**Figure 4.** The primary frequency control droop and deadband actual values estimation for the operation of Karmanovskaya TPP unit 2 on 20.03.2016 (the existing method - a, the alternative method - b).
Figure 5. The primary frequency control droop and deadband actual values estimation for the operation of Permskaya TPP unit 3 on 12.03.2016 (the existing method - a, the alternative method - b).
The values of deadband and droop obtained by different methods are given in tables 1 and 2.

**Table 1.** The values of deadband obtained by different methods.

| TPP, unit, date | The existing method | The alternative method | Setpoints |
|----------------|---------------------|------------------------|-----------|
|                | Left border, (Hz)   | Right border, (Hz)     |           |
| Karmanovskaya  | -0.024              | 0.024                  |           |
| TPP, unit 2,   | -0.0135             | 0.0125                 | -0.015    |
| 20.03.2016     | 0.015               | 0.015                  |           |
| Permskaya TPP, | -0.033              | 0.033                  |           |
| unit 3,        | -0.0135             | 0.0155                 | -0.015    |
| 12.03.0216     | 0.015               | 0.015                  |           |

**Table 2.** The values of droop obtained by different methods.

| TPP, unit, date | The existing method | The alternative method | Setpoints |
|----------------|---------------------|------------------------|-----------|
|                | Left part, (%)      | Right part, (%)        |           |
| Karmanovskaya  | 2.6                 | 2.6                    | 4.7       |
| TPP, unit 2,   |                     |                        | 6.1       |
| 20.03.2016     |                     |                        | 5         |
| Permskaya TPP, | 2.4                 | 2.4                    | 6.1       |
| unit 3,        |                     |                        | 5.9       |
| 12.03.0216     |                     |                        | 5         |

Thus, we can see that the alternative method gives more adequate and reliable estimation.

**Conclusion**

The existing method for primary frequency control droop and deadband actual values estimation sometimes doesn’t work properly. The alternative method, which allows estimating droop and deadband actual values more accurately, has been developed.

**References**

[1] The order of determining the volume of SPFC services, Appendix 2 - Criteria for monitoring the participation of generating equipment in the SPFC (Moscow: «System Operator of the United Power System», Joint-stock Company)