Process Dynamics
Part 2
Online PSI and Frequency Analysis

Introduction

Previously, we explained with examples how to consider the stability/instability of plant operation by applying clustering technology, which is also evaluated as AI technology, to time series data collected by PIMS (Plant Information Management System). In addition, the Process Stability Indicator (PSI) developed by us, which quantifies stability/instability from the clustering analysis results, is also introduced.

When the process is divided into several sections and the PSI in each section is evaluated, it is also explained that further in-depth process operation stability / instability examinations such as whether the operation of the entire process is more stable or unstable than before, and whether the instability of one section affects other sections can be performed accurately and quantitatively. In addition, by the five-step stability evaluation with the results of PSI, it was also shown that the operation of the section can be judged by the program whether "stable, a little unstable, unstable, very unstable, extremely unstable". This makes it possible for engineers with insufficient experience or knowledge to lead accurate assessments, since stability/instability assessments do not rely on the technical capabilities or experiences of engineers. In Part 2, we will first discuss the reports that are automatically generated by the clustering application we developed. Then, online clustering application and frequency analysis with wavelet transformation will be described.

1. Review of Part 1

1) The fact that the operation of the process plant is unstable means that the dynamics (dynamic characteristics) of the equipment and equipment are unstable. However, it is difficult for process engineers and operations engineers to understand the dynamics of the equipment they are responsible for. In addition, it is not even obtained how to catch dynamics.

2) DCS (Distributed Control System) and PIMS (Plant Information Management System) are systems for collecting data on process unit operation. DCS can display short-term data, but it does not have the function of grasping dynamics. PIMS has simple dynamics grasp function such as FFT (Fast Fourier Transformation), but it is left to the engineer to judge the calculation result.

3) The dynamics of the unit and equipment are possible to grasp by displaying the trend screen, but if the stability / instability of the process is evaluated, all Tags pertaining to the unit must be displayed, and it is not possible with the current DCS or PIMS. Also, even if the

data of all Tags can be displayed, it is almost impossible to read stability /instability from there.

4) In "clustering", which is estimated one of AI technologies, it is a technology that can infer another conclusion from the result because the data is classified by allocating the given data to multiple clusters. For example, with simply classifying by the length and the width of the iris petal, it can be classified almost accurately by type of iris even if there is no information on the type.

5) This clustering is applied to fault detection (abnormality detection) in process operation. Examples of applying clustering as below are shown.

(1) confirmation of operation stabilization by APC (altitude control)
(2) accurate identification of operation instability period
(3) identification of stable / unstable period in batch operation cycle
(4) detection of periodic fluctuations in continuous operation

6) In order to quantitatively evaluate the results of clustering, we have developed the Process Stability Indicator (PSI) as a new index. The results of PSI are evaluated in the following five stages.

100% ≧PSI>90%	Stable
90% ≧PSI>80%	A little Unstable
80% ≧PSI>70%	Unstable
70% ≧PSI>60%	Very Unstable
60% ≧PSI	Extremely Unstable

7)PSI and its evaluation enable stability and instability assessment of process operation without relying on engineer subjectivity. In addition, by applying it over time, dynamic evaluation can be performed if the unit operation is moving toward the stable direction or the unstable direction.

2.CPCon package

The application package we developed is called "CPCon".

CPCon includes the following functions for applying data analysis and analysis results.

1) Time series data analysis by clustering
2) PSI calculation and resulting stability/instability evaluation
3) Online clustering calculation and PSI evaluation
4) Noise switching by wavelet conversion
5) Periodic variation analysis by fractal dimensional calculation results of each noise
6) HFSI (High Frequency Stability Indicator)
7) Stability/instability evaluation in the high frequency band by calculation and resulting Wavelet & Fractal calculation and HFSI evaluation

8) SISO (Single Input Single Output) model predictive control based on impulse response
9) Stabilization control using SISO model prediction control and PLS (Partial Least Square: partial least square method) Quality control
6)-9) will be explained at the next Part 3.
CPCon also has the capability to support process engineering reports, which is briefly explained next.

3. Clustering calculation and PSI evaluation support function
When the clustering application of CPCon is applied, the files shown in Fig.1 is automatically generated in a new folder with the process unit name.

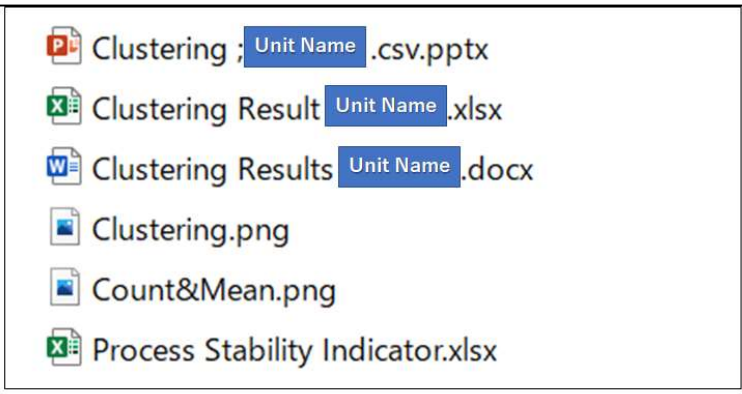

Figure-1 Files automatically generated by Clustering application

1) PowerPoint file (Fig.2): File includes a trend graph of clustering calculation results and PSI calculation with evaluation.

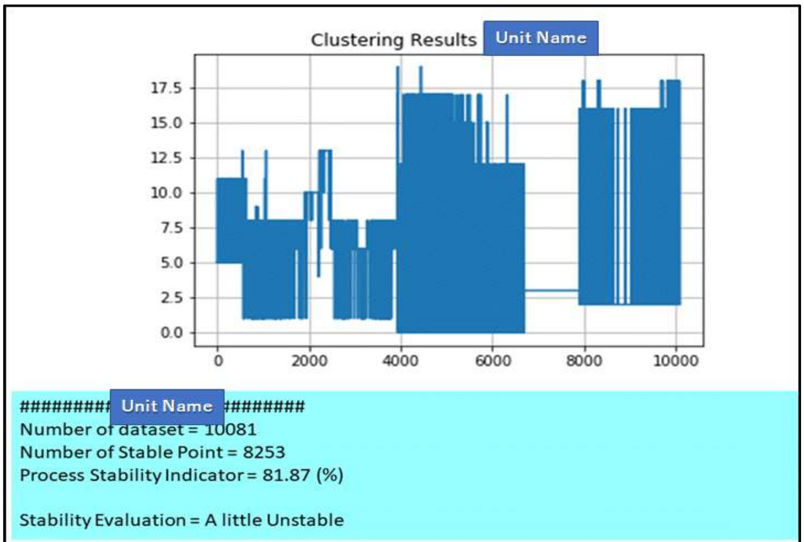

Figure-2 Power Point file with Clustering application results

2) Excel file (Fig.3): A file containing the data used for clustering and the calculation results (count for each cluster, average value for each)

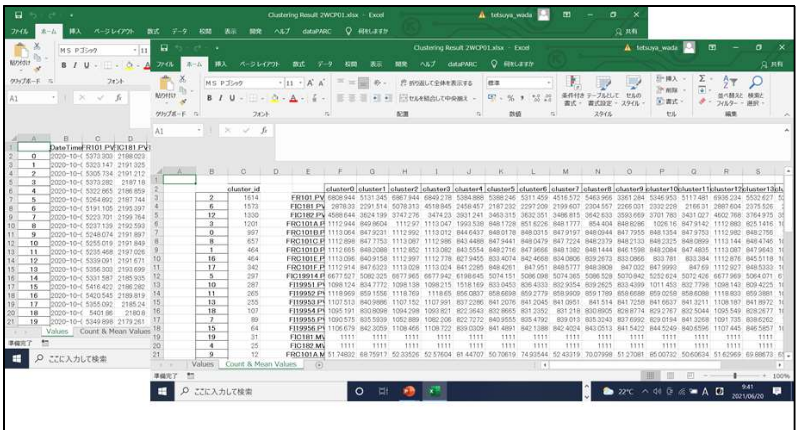

Figure-3 Excel file with Clustering calculation results

3) Word file (Fig.4): Basic information such as number of Tags used for clustering, tag names and unit of each, number of data, start and end time of data, time executed clustering calculations, resulting trend graph, graph of count and average value per cluster, and file containing PSI calculation and evaluation results.

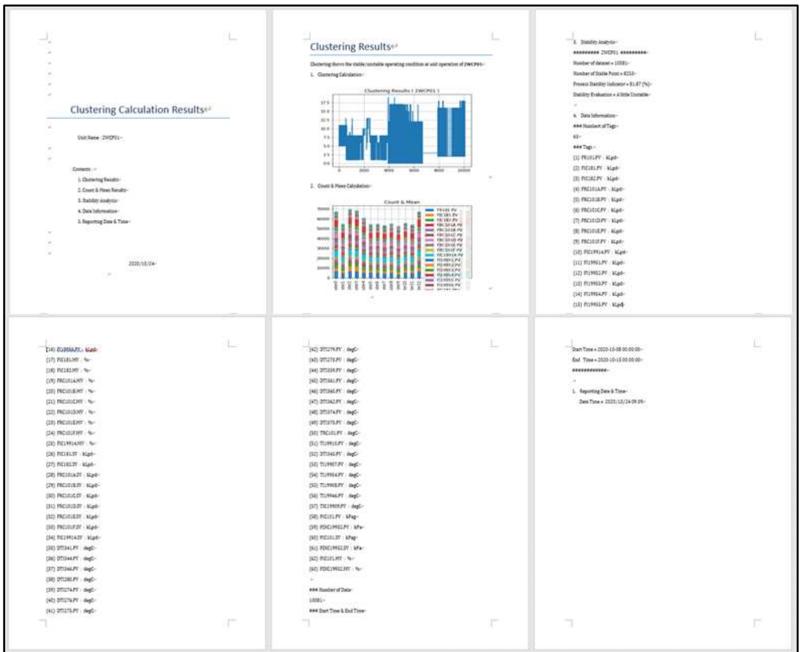

Figure-4 Word file with clustering calculation results

These three files make it easy for users to create reports. Word files can also be used as reports as they are. By using files of the same template, the reporting format can be unified, so that the subjectivity of the engineer does not enter into the report of the data analysis, and it is easy to understand in the report of other engineers. For engineers who want to create further cast-me-down reports, trend graphs of clustering results, graphs of counts and average values for each cluster, and Excel files as PSI calculation results are also individually generated in folders.

4. Online clustering and PSI evaluation

When process engineers analyze data at present, the function of PIMS is not enough, so it is the most common way to download past data from PIMS to an Excel file and perform various examinations using the data of the Excel file. And, it takes unexpectedly time to this work. Why can't PIMS data be communicated directly to data analysis applications? It is because most applications don't have the capability to retrieve data directly from PIMS. To do this, engineers must manually bridge the data. This is utterly stupid. CPCon, which we developed, has the function of automatically retrieving data from PIMS online. FIG. 5 is a configuration diagram of a system in which CPCon acquires data from PIMS. Al omitted here, the OPC server is connected to DCS.

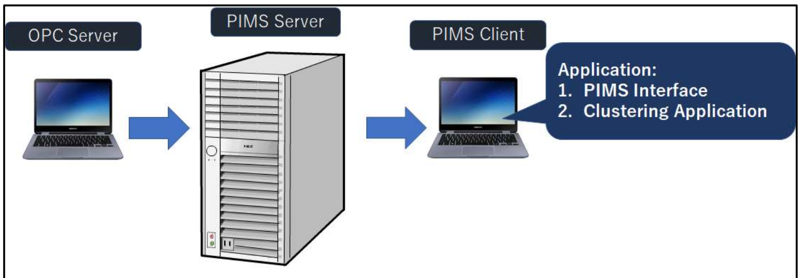

Figure-5 Systems structure of Online Clustering

The PIMS server acquires and stores process operation data from DCS via OPC server. It is the role of the PIMS client to take out the data stored on the PIMS server and display it on the trend screen.

All CPCon online clustering applications are installed on this PIMS client. It is an interface application for retrieving data from a PIMS client and a clustering application that uses that data to perform calculations and automatically generate folders and files.

PIMS has a variety of applications, most often used: PI (OSIsoft), IP21 (Aspen Tech), Uniformance (Honeywell), and dataPARC (Capstone).

CPCon's interface applications support these PIMS, and PI can be interfaced in older versions.

CPCon collects data from PIMS clients, so if there is a limit on the PIMS client, it will not collect data more than the limit. In other words, when data is collected with CPCon, there is no extra load on the PIMS server than designed.

In CPCon, the data collected by the interface application is processed directly to the clustering application, so there is no need for engineer intervention. If the engineer fills out a sheet with the unit to which clustering is applied and the Tag names pertaining to the unit in advance, CPCon automatically reads the sheet, collects data using the Tag names described therein,

and performs clustering calculation. The duration and width of data collection can be arbitrarily set. In addition, as a standard, the collection of data for one minute from the time CPCon is operated to two weeks ago is set. The clustering application is also provided with all the functions described in "3. Clustering calculation and PSI evaluation support function". That is, calculation results and related data are stored as PowerPoint files, Excel files, Word files and image files in an automatically generated folder.
Therefore, CPCon automatically executes and generates data collection of pre-decided Tags and periods, clustering calculations and PSI calculations with evaluations using collected data, and a set of files for reporting including all data and results, just by executing the application. Engineers is not to assess the stability/instability analysis of process operations as time-consuming as before, but to go a step further in identifying and investigating the causes of instability in units defined by application.

5. Identification of dynamics by frequency analysis
In order to operate the process unit, equipment such as pumps, compressors, heating furnaces, and distillation towers that make up the process unit must be moved individually. However, it is difficult to achieve the required performance just by moving the equipment. For achieving the required performance, it is necessary to correctly control the flow rate, temperature, pressure, etc., and demonstrate the performance of individual equipment.
Dale E. Seborg and others wrote "Process Dynamics & Control: Industrial Technology Publishing, translated by Tetsuya Wada et al.", which addresses process control even from Chapter 1 to explain why process dynamics are necessary. Let me introduce the beginning of Chapter 1. "Recently, it has become very difficult to drive a process plant with the required performance satisfied. We must strictly regulate and drive our product nature due to factors such as increased competition, tighter environmental and safety regulations, and a rapidly changing economic environment. In addition, this creates more complexity for operation, since even though the recent processes are large and highly centralized, only small surge drums are installed between process units. In such a plant, the operation variation is easily transmitted from one unit to another. Therefore, the importance of process control in operation is increasing year by year in the process to safely and effectively perform unit operation. In fact, it is almost impossible to drive state-of-the-art processes operation safely and efficiently without process control and with satisfactory product quality. “
What is written here is that product quality, safety, and efficiency in process operation cannot be satisfied without stable control of the process unit. So, the question is what is the "stable control"? We believe that "stable control" is "control that minimizes the influence of disturbances on the control system and produces requires products". Therefore, if the effects

of disturbances are accurately identified, the stability/instability of the control system can be examined. There are two types of disturbances that affect the control system. One is disturbances that are considered as step inputs such as a decrease in the raw material supply amount, an increase in fuel gas pressure, and so on. This disturbance is a disturbance that is considered in advance when researching control system, and the control system is designed to quickly settle the fluctuations due to this disturbance. Therefore, process engineers should only consider the response of the control system, and it is not necessary to consider stability/instability created with this disturbance. The second disturbance is commonly called "noise". This is including the noise that is not originally related to process operation by electronic devices, etc., and the noise caused by fluctuations in other devices and control systems. The former noise is white noise (noise that can be ignored). The latter noise is black noise (noise that cannot be ignored) or gray noise (noise that should not be ignored). The difference between white noise and black noise (gray noise) is that white noise affects the entire frequency band in the same way, while black noise (gray noise) affects only a specific frequency band. Black noise (gray noise) must be considered when it comes to controlling process operation.

However, if this black noise (gray noise) affects only the low frequency band of the process operation, it may be considered in the same way as the control for the step input. It is necessary to investigate the cause in more detail and repair the cause if the noise affects the high frequency band of the process operation, in which case the noise causes fluctuations in the response of the control system itself. Though, even if we say noise for each frequency band and its sorting, readers and general process engineers will not understand what to do. One of the answers and the most effective technique is wavelet transformation. We have applied this wavelet transformation to the analysis of noise in process operation in many factories where we have consulted and introduced CPCon, with effectively enough results until now.

6. Wavelet transformation

Previously we described that the operation data of the process can be analyzed stability / instability using clustering as time series data. If the operation data of the process is viewed from another angle, it can be said that the final trend component is data containing a number of noises from the low frequency band to the high frequency band. For example, in FIG. 6, the gentle waveform in the center is a trend component, and the actual data that fluctuates greatly is considered as a number of noises cumulated on the trend component.

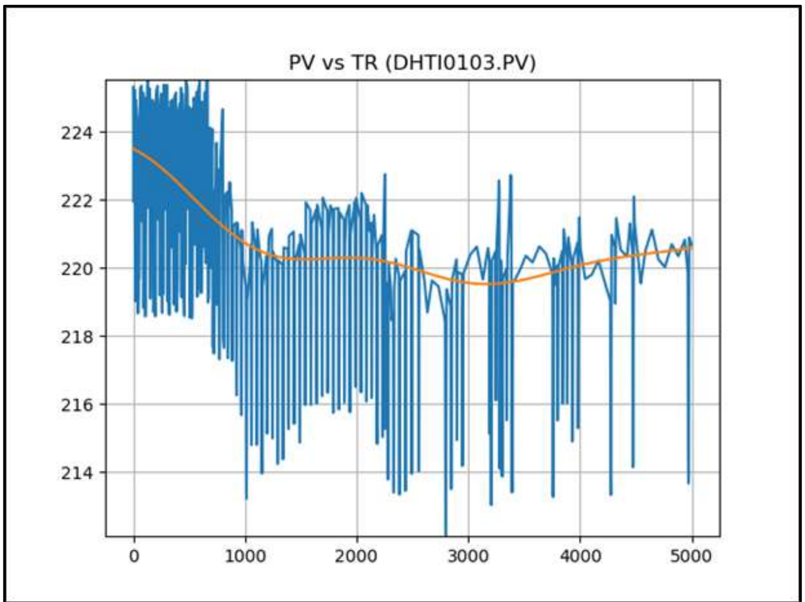

Figure-6 Real data vs Trend data

Therefore, when considering the fluctuation caused by noise, it is necessary to separate the noise for each frequency band and consider the degree of variation of the separated individual noise. Then, how should the noise of each frequency band be separated? It is a wavelet transformation to give the answer. Wavelet transformation is a technique that sequentially separates noise from the high frequency band using a waveform called a wavelet. FIG. 7 is a commonly used wavelet waveform. This waveform, named after the developer, is called a Meyer wavelet.

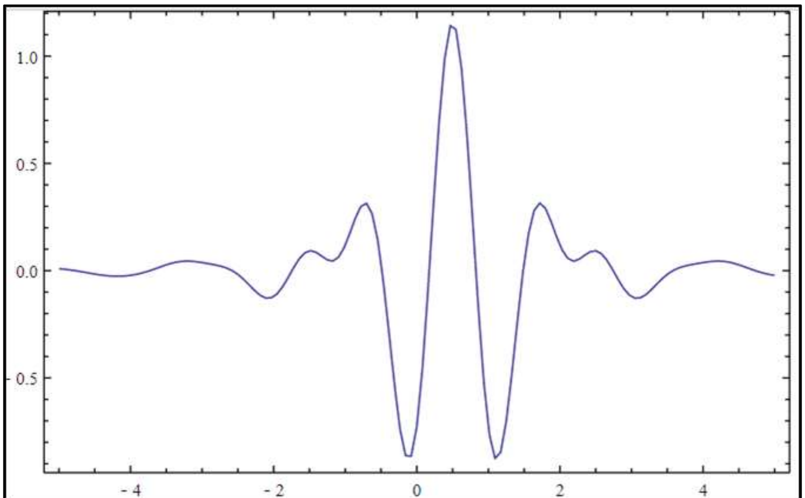

Figure-7 Wavelet waveform (Meyer Wavelet)

When used in discrete systems, this waveform may be digitized at regular intervals. However, it is important that the sum of the numbers becomes 0 (zero).

FIG. 8 is an example of noise separated by applying a wavelet transformation. In this example, the wavelet transformation is applied 10 times to separate noise from the high frequency band to the low frequency band. (1) is the noise in the highest frequency band, and (10) is the noise in the lowest frequency band.

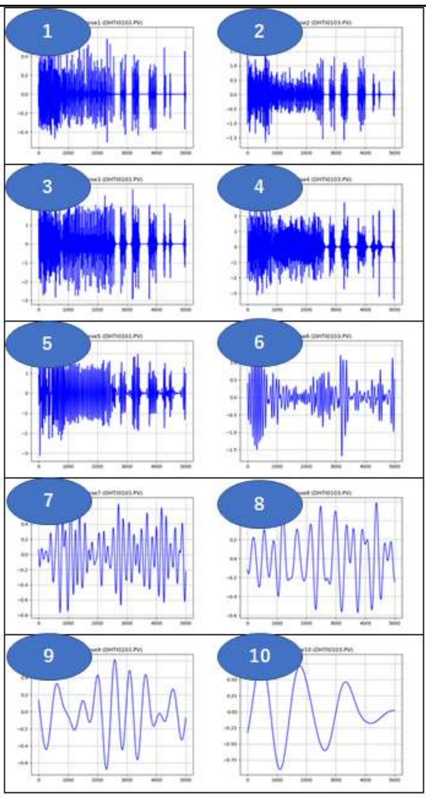

Figure-8 Noises separated by Wavelet transformation

In this example, it can be seen that there is a variation in the noise of the high frequency band in particular. In addition, since the horizontal axis is a time axis, it is possible to read such information as to when the noise fluctuations began and when they settled down.

7. Analysis example by Wavelet transformation

This is an example of examining the tower bottom level fluctuation of a distillation tower. When a level fluctuation occurred in this distillation tower, there was no change in the top pressure of the tower, the amount of raw material flowrate, and the fuel gas adjustment valve opening (OP) for the reboiler. (Figure 9)

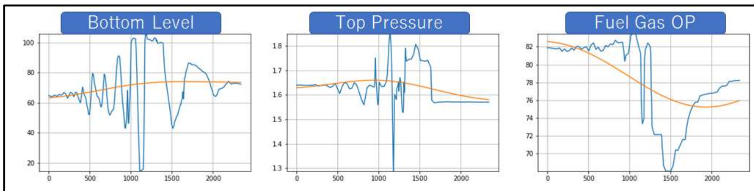

Figure-9 The trend from starting fluctuation to settling it

The tower bottom level suddenly began to fluctuate without any change. The operator did not know the cause, but thought it was a temporary fluctuation and would soon be settled, and made no adjustments. Then, the fluctuation became larger and larger, and finally exceeded 100% of the level. The operator quickly narrowed down the valve opening of the reboiler fuel gas. Then, the tower bottom level descended at a glance this time. Therefore, the operator hastily increased the valve opening. As a result, the tower bottom level exceeded 100%, and the valve opening had to be narrowed down again. For a while, such a change in the tower bottom level and the fuel gas valve opening degree to correspond were adjusted, but as a result, a large fluctuation occurred in the tower top pressure, and the product became off-spec, leading to long-term product loss. The reason why the fluctuations began was not known even after the driving became stable.
Therefore, we applied wavelet transformation to the tower bottom level data to cut out noise from high frequency to low frequency. The result is Fig. 10.

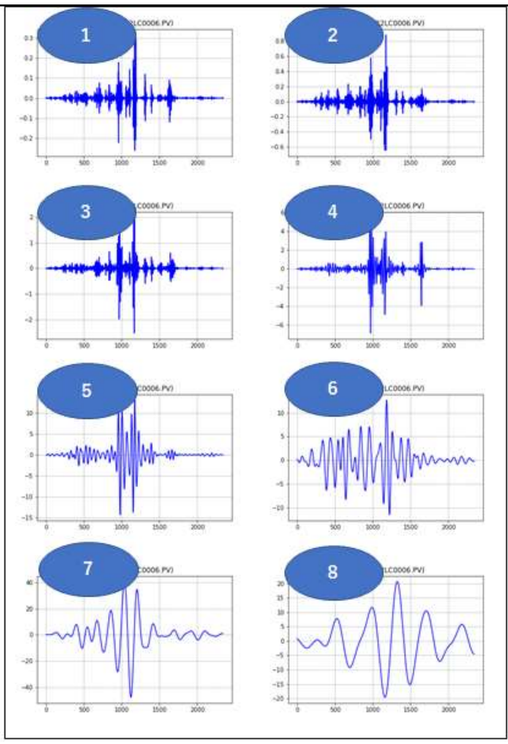

Figure-10 Noises separated by Wavelet transformation

From this result, it was found that the fluctuation of the sixth noise was large, so the sixth noise was compared for the tower top pressure, the fuel gas valve opening degree, and the fuel gas flow rate, which is usually proportional to the valve opening. (Fig. 11)

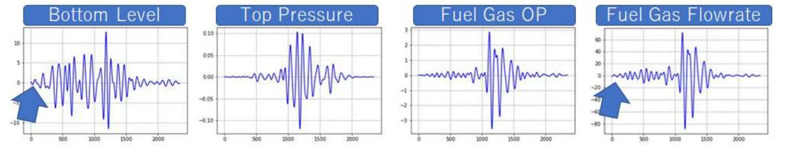

Figure-11 Comparison of sixth noises separated by Wavelet transformation

From this comparison, it was found that the valve opening of the fuel gas did not change, but the fuel gas flow rate fluctuated, which caused the fluctuation of the tower bottom level. Since the fuel gas is piped from outside the device, it was inferred that the fluctuation of the fuel gas flow rate due to the pressure fluctuation of the fuel gas system caused the fluctuation of the tower bottom level. They also found that the sixth noise had significant changes, so it fluctuated over a period of 1 to 2 hours. Thus, if wavelet transformation is applied to confirm the stability / instability of the noise of each measurement data, it is likely to be found the detail information which clustering cannot get, such as what causes it, when it started and when it settled down, and how much the period of fluctuation was.

In addition, as in this example, wavelet transformation shows a greater effectiveness on stability/instability analysis of process operation than clustering, but it is currently qualitatively evaluated by looking at separated noises and trend. Therefore, we applied a fractal dimension to the cut-out noise to quantify it. As with clustering, we have also developed HFSI (High Frequency Stability Indicator) for stability/instability evaluation with high frequency band. Of course, the development of online and automatic file creation applications has also been finished for wavelet transformation. In the next part, these details will be described, including further examples of wavelet transformation application.