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Flexibility Study on Site-Modeling

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Abstract

In this paper, we conduct the flexibility study in a utility plant for the large-scale chemical production site. It is known that utility plant is usually designed based on its nominal operating condition with attractive economic return. However, because of the fluctuating supply / demand on raw material / product (uncertainty) for the site, it is difficult to design the high efficiency and flexible utility plant. Principally, a good plant design should not only show an optimal balance between capital and operating costs, it must also show an feasibility characteristics which allows economic performance to be applicable in a general operating environment. Hence, the ultimate goal is let plant professionals plan, monitor and manage the plant flexibility in which the future supplies and demands are under uncertainties. For that reason, we would like to introduce an uncertainty study to stabilize the “Utility Plant Flexibility”. In fact, by ignoring the historical data of variations, the plant professionals of course can build a very big plant to deal with all the uncertain situations; however this kind of movement is definitely impractical and inefficient. Thus, the first step we have to define “Flexibility does not imply oversize design of utility plant”.

This paper will introduce a new concept to measure the utility plant flexibility based upon the uncertain parameters. Basically the concept is foundation on the Grossmann’s idea on flexibility measurement. It is believed that with proper flexible operation in the utility plant, the overall energy usage will be rationalized that generates merit to the company.

Keywords: Optimization; Site-Modeling; Uncertainty; Flexibility; Flexibility Index

1. Introduction

The general concept about "Flexibility" is familiar for people. A utility plant, which is able to operate under various environments, is regarded to be more flexible than the other plants [1]. Usually these changing environments are affecting the normal plant operation. If the plant can operate well under uncertainties, this will allow it to make attractive profit [2]. Therefore, flexibility study becomes an important issue during designing and operating the plant. However, researchers still lack of unique definition of flexibility and also its measurement. This causes the optimization on plant flexibility to be difficult.
In 1983, Grossmann and his coworkers [3-4] were first handling on the formulation of flexibility. They proposed quantitative index, Flexibility Index (FI) on its measurement. The idea was used to help designers locating the limitation (feasible space) of the given design and indicating the operability of the given process over uncertain parameters. It also provides the important information to retrofit the process design for improved process flexibility when some parameters touching their limits [5]. Therefore, the appearance of FI brings flexibility concept into more analytical modeling level.
In Grossmann's definition, FI takes the shortest distance between the nominal point and the boundary [3] (could be process constraints or uncertain parameter limits) of the process. However, this definition is not sufficient to provide comprehensive evaluation of process flexibility in some situations. For example, two designs are shown in Fig. 1, Design 1 and Design 2, they have the same FI, but Design 1 is obviously preferable than 2. However, due to the same limitation at one particular space (i.e. same critical pt from nominal pt to the nearest boundary), this generates the same Grossmann's FI for both designs. Eventually, this will give a wrong message to the designers.
Hence, it is necessary to improve the current index, such that the new index can show significant information of the process flexibility. In this paper, the new flexibility index is introduced. Afterwards, its application is illustrated with examples and then discussed in the last part of this paper.

2. Process Flexibility Index

2.1. New Flexibility Index and its Definition

Generally, there are many uncertain parameters in a chemical process. Each uncertain parameter, (θ_i), have its expected upper and lower limits, $\theta_{i,U}$ and $\theta_{i,L}$. Inside the limit, the process can be handled with confidence. The space bounded by all upper and lower limits of the uncertain parameters is representing the whole space consisted of all the possible combinations of the uncertain parameters and we define this space as S_o:

$$S_o = \left\{ \theta(\theta_i) \middle| \, \theta_{i,L} \leq \theta_i \leq \theta_{i,U} \quad i = 1, 2, ..., N \right\} \qquad \text{Eq. (1)}$$

where N = number of uncertain variables

In addition, there are many process constraints in a process, which forms a constrained space, S_c, such that the process is operated without process constraint violation. The S_f is the union of S_c and S_o in the space:

$$S_c = \left\{ \theta \, \middle| \left[\, \exists \, z \mid f(d, z, \theta) \leq 0 \, \right] \right\} \qquad \text{Eq. (2)}$$

where $f(d, z, \theta) \leq 0$ = feasible region bounded by the constraint boundary
z = control variables, d = design variables

$$Thus \quad S_f = S_o \bigcup S_c \qquad \text{Eq. (3)}$$

The new flexibility index, FI_V, is then defined as the ratio of S_f to S_o. From the Fig. 2, the size of S_f is the area within the process constraint boundary A_f, while the size of S_o is the area A_o bounded by the expected limits boundary. The new flexibility index, FI_V can be expressed as:

$$FI_V = \frac{A_f}{A_o} \qquad \text{Eq. (4)}$$

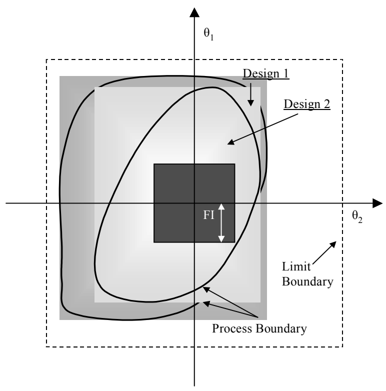

Fig. 1. Same FI with dif. process flex.

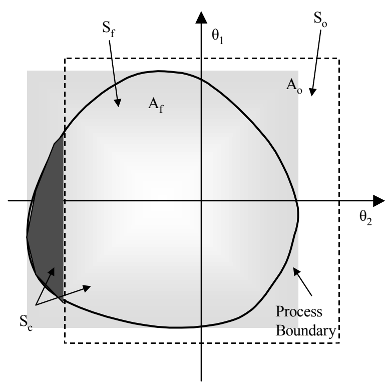

Fig. 2. The new FI_v.

3. Site-Modeling Flexibility Study

3.1. Demonstration Example

The demonstration example will be first used to compare the Grossmann's FI

and the new FI_V. A model containing one turbine is supplying low pressure steam (LPS) and electricity (EL) to a site. Assuming that high pressure steam (HPS) and condensate (COND) have upper and lower limits with uncertain demands of LPS and EL. Nominal values and deviations of LPS and EL are given in Fig. 3. It is assumed that the probabilities of these uncertainties are equally distributed inside their ranges.
By using the Grossmann's definition, the calculated FI was 0.53 (Fig. 4, the square). However, it is obvious that the actual operation space (S_f) should be much larger. Therefore, the key point is to find proper estimation approach for finding the feasible space, S_f. As a result, we consider 4 vectors radiate outward from the nominal point (Fig. 4), such that each vector has to be optimized. Thus, the optimized area (trapezium) inside the feasible space can generate better result than Grossmann's idea. Finally, the FI_V was 0.7.

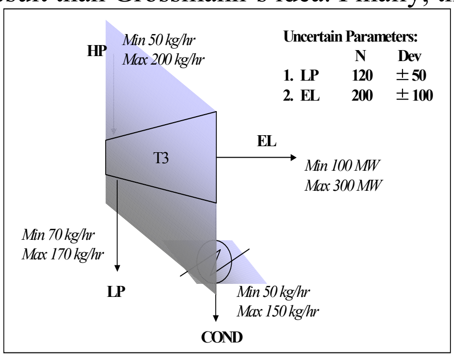

Fig. 3. Turbine Example.

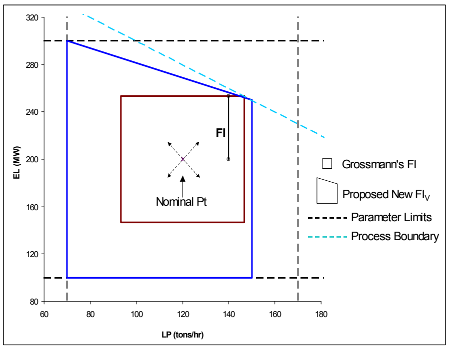

Fig 4. FIs Comparison.

3.2. Site-Modeling Example

Now we turn our focus to a more substantial case, Site-Modeling case [6]. A utility plant generating steam and EL to the chemical site is demonstrated in the Fig. 5. The utility plant contains one boiler, two back-pressure turbines (T1 and T2) and one condensing turbine (T3). It supplies LPS and EL to the production site. Assuming that the demand of LPS and EL are equally distributed with the nominal values are 60MW and 240T/H respectively. The deviations of LPS and EL are ±25MW and ±15T/H.

3.2.1. Base Case:

From the given uncertain condition of LPS and EL demands together with the existing process constraints, we can optimize the existing plant and calculate the FI_V. In the base case, the FI_V is 0.48. Actually, the value is smaller than expectation, which means the plant is not feasible enough. From the Fig. 6, it found that the scaled positive deviation of EL is limited at +0.6, which makes the feasible space (S_f) to be limited. By checking the current operating condition, it is found that there is 68T/H HPS let-down to LPS directly. Actually this excess HPS can be used for EL generation and improving the EL flexibility.

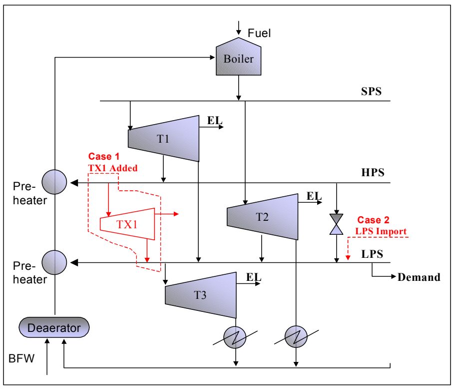

Fig. 5. Utility Plant Layout.

3.2.2. Case 1:

We then consider utilizing the excess HPS steam by installing a new back-pressure turbine (TX1, HP-LP turbine) between the HPS and LPS headers. After installing the TX1, the overall FI_V is increased to 0.56 (Fig. 7). The increased FI_V is mainly come for the increased EL space. However, the flexibility of LPS is still severe as its scaled positive deviation is very limited. For this reason, it is worth to investigate how this severe condition could be ease and get more flexibility to the plant.

3.2.3. Case 2:

Assuming that there is additional LPS importing to the LPS header directly. The inputted amount was 10T/H. This acts the supply of LPS to be more flexible for the utility plant. From the optimization result (Fig. 8), the FI_V is greatly increased to 0.87, which is about 55% more than case 1. Hence, the bottleneck was actually located at the LPS generation. By improving the LPS supply condition, the feasible space of the utility plant has been increased, which means the utility plant can handle more different LPS and EL combination cases. Hence, the FI_V is the best signal telling us how to improve the utility plant flexibility by making proper adjustment / modification.

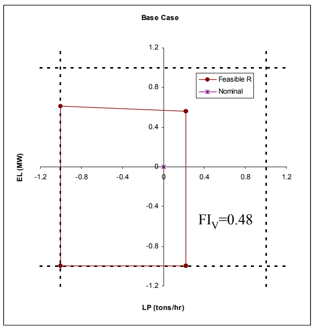

Fig. 6. Base Case.

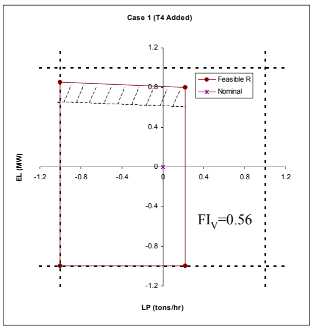

Fig. 7. TX1 Added.

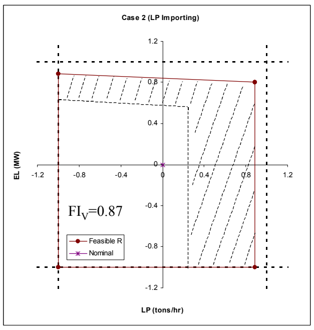

Fig. 8. LPS Import.

It is noticed that the Fig. 6 to 8 are plotted with the scaled axes.

4. Conclusions

A new proposed flexibility index measurement is proposed to supplement of the current flexibility indices. The new index is measured the ratio of the feasible region to the size of the region consisted of all combinations of the uncertain parameters within their expected upper and lower limits. The index can provide comprehensive measurement of the whole feasible region in the uncertain space. We believe the proposed new index is able to provide informative idea about the process flexibility and generates merit to the company.

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