Advances in Engineering Research, volume 185
2nd International Conference on Electrical and Electronic Engineering (EEE 2019)

A Flexible Over-Frequency Generator Tripping Method Based on Power Flow Tracing

Yi-xuan CHEN[1], Zhi-hang ZHOU[2,*], Ye HE[1], Ling-fang LI[1] and Li-bao SHI[2]
[1]Research Centre of Power Grid Planning, Yunnan Power Grid Company, Yunnan, China
[2] National Key Laboratory of Power Systems in Shenzhen, Graduate School at Shenzhen, Tsinghua University, 518055, Shenzhen, China
*Corresponding author

Keywords: Frequency stability, Asynchronous interconnection, Over-frequency generator tripping, Power flow tracing.

Abstract. With the rapid development of DC transmission in recent years in China, frequency stability has become a key issue for the normal operation of the entire asynchronous interconnected electric system. When the external DC transmission line experiences a fault, the frequency of the electric grid at sending end will inevitably rise, which may further cause frequency stability problem. Therefore, in order to prevent system frequency instability, over-frequency generator tripping devices are widely installed in major power plants. This paper proposes an over-frequency generator tripping scheme based on the power flow tracing technology. Some significant strategies including predetermination of maximum generator tripping capacity in each round, calculation of the power flow contribution level for each generator, sorting and grouping of generators to be tripped, optimized proportion of generator tripping, and the inspection of over tripping phenomenon are discussed elaborately. Finally, the validity and effectiveness of the proposed strategy is verified by conducting case studies.

Introduction

After the asynchronous interconnection through DC transmission, frequency stability will become one of the main factors threatening the safe and stable operation of the power grid [1]. It is known that the power system frequency is closely related to the active power, and the frequency change is affected by the generator output adjustment, the load power fluctuation and so on. When the power supply provides more active power than the load demand, the system power is excessive, and the frequency will increase. On the other hand, when the power supply is less than the load demand, the system power is insufficient and the frequency will decrease. Due to the constant change of load power, and coupled with the uncertainty of the current large-scale access to new energy power generation devices such as wind power and photovoltaic energy, the power of the entire power system is in a real-time dynamic balance. In normal operation condition, although the system frequency fluctuates, it does not change much and remains stable at around 50 Hz.

Frequency stability is the premise of stable operation of power system. After large-scale DC transmission projects have been put into operation one after another, the current power grid presents a trend of asynchronous interconnection. At this time, if the DC line fails, it will cause a large power surplus and a series of frequency stability problems. As a measure of stability, the over-frequency generator tripping device monitors the system frequency above the allowable frequency, and then cuts off some generators after a short delay, so that the entire system frequency can be restored to the power frequency 50Hz.

Traditional over-frequency generator tripping measures are limited to a specific historical background, and bear the following shortcomings [2,3,4]:

1) Based on subjective experience and lack of theoretical guidance.
2) Poor flexibility and not suitable for different modes of operation.
3) Easy to cause overcut or undercut of generators.

4) Fail to take into account a series of new problems, such as the stability of large-scale HVDC transmission lines after blocked, etc.

Therefore, if the capacity of the generator unit to be tripped can be flexibly determined according to the actual fault current, it not only complies with the principle of minimum cutting, but also meets the requirements of large-scale DC asynchronous interconnection. Regarding the deficiencies of the traditional over-frequency generator tripping scheme, we proposes a flexible method for the over-frequency generator tripping pertinent to the AC-DC system in this paper. We aim to seek appropriate tripping capacity in accordance with the principle of minimum tripping generator. This paper is organized as follows. Flexible over-frequency generator tripping method is described in Section II. A hybrid AC/DC power system is provided as an example to demonstrate performance of this method, the details can be found in Section III. The final conclusions are given in Section IV.

Over-Frequency Generator Tripping Method

In the preprocessing, the maximum generator tripping capacity of each round is determined. Firstly, the outgoing transmission line of the regional power grid is disconnected without failure, and the island grid operation of the regional grid is simulated. Subsequently, by gradually increasing the regional power grid generator tripping capacity, when the system frequency just reaches the first round of under frequency load shedding action value, the generator tripping capacity is determined as the maximum generator tripping capacity P_{max} at each round.

In this paper, the power flow tracing method is used to calculate the power flow contribution level of each generator after a line fault [5]. As shown in Fig. 1, point i is a node in the power grid, $P_{in,1}$, $P_{in,2}$, $P_{in,3}$…$P_{in,m}$ are the powers flowing into the node for each branch, $P_{out,1}$, $P_{out,2}$, $P_{out,3}$... $P_{out,n}$ are the powers that the node flows to each branch. For node i, the power of each branch flowing into node i must be equal to the power flowing from node i. Taking the outflowing j-th branch as an example, according to the idea of power proportional distribution, the power flowing out of the j-th branch $P_{out,j}$ is provided by aggregated powers from the 1st node injected power $P_{in,1}$ to the m-th power $P_{in,\mathrm{m}}$ as shown in Fig. 1. Therefore, the power provided by the i-th flow into the branch $P_{i\text{-}j}$ is:

$$P_{i-j} = \frac{P_{in,i}}{\sum_{k=1}^{m} P_{in,k}} P_{out,j} \tag{1}$$

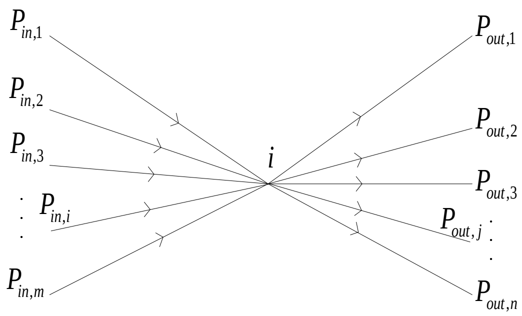

Figure 1. Tracing power flow of node *i*

In the actual power system, the power flowing into the node includes not only the transmission power between nodes, but also the power injected directly by the generator set near the node. When the system is running normally, the transmission power from the node i to the adjacent node q is P_{iq}. If the line i-q has a fault, such as DC blocking, the system will have surplus power P_{iq} that cannot be sent at this time:

$$P_{iq} = \frac{P_{iq}}{P_i} P_i = \frac{P_{iq}}{P_i} \sum_{k=1}^{n} [A^{-1}]_{ik} P_{Gk} \tag{2}$$

Where, P_i is the input power of the node i , P_{Gk} is the generator power at the node k, and A is the power flow backward tracking coefficient matrix. In the actual power system operation, line losses are relatively small. Accordingly the elements a_{ij} in the matrix A satisfy the following equation:

$$a_{ij} = \begin{cases} 1 & i = j \\ -\dfrac{P_{ji}}{P_j} & i \neq j \text{, and } j \in D_i \\ 0 & \text{others} \end{cases} \tag{3}$$

Where, P_j is the input power of the node j, P_{ji} represents the transmission power of the node j to the adjacent node i through the line, and D_i represents the set of nodes that all powers flow to and are connected to the node i. Therefore, the Power Flow Contribution (*PFC*) of the faulty line generator node can be defined as:

$$PFC_k = \frac{P_{iq}[A^{-1}]_{ik}}{P_i} \tag{4}$$

The *PFC* ranges from 0 to 1, and it measures the proportion of injected power of different generator nodes in the line power flow. When the *PFC* of a certain generator node is larger, it indicates that the generator contributes more to the current flow of the line, and the more it should be cut off.

In practice, the *PFC* of multiple generator nodes may be similar. If we cut off the generator units one by one according to the value of *PFC*, it will undoubtedly increase the complexity of the over-frequency generator tripping. Therefore, the grouping method can be used to simplify the generator tripping process.

After calculating the *PFC* of each generator node, it is sorted according to the value of *PFC*. Then the generators can be divided into several groups according to a certain step size, and the more generator units in the larger PFC group should be removed.

Therefore, *PFC* can be divided into three groups: highly correlated group [*a*, 1], generally correlated group [*b*, *a*), and relatively low correlated group [0, *b*). Among them, the value of *PFC* can be determined according to the actual situation of local power grid. Through a large number of simulations, this paper gives a set of empirical reference values: a=0.3, b=0.15.

The *PFC* value of the generator node indicates the correlation between the generator node and the excess power. Therefore, when the value of *PFC* is larger, the capacity of the generator that should be removed from the system will be larger accordingly. Combined with the above ideas, this paper adopts the method of optimizing the ratio of the generator tripping to further improve the tripping speed of the generator unit, thus effectively suppressing the system frequency from increasing and accelerating the system frequency recovery.

According to the local power grid, the capacity of each round of generator tripping is determined as c% of the total capacity of generator units, such as the empirical value: c%=5%. After sorting the *PFC* of each generator node, we can select the median as the reference value of the *PFC* (PFC_{ref}), or determine it based on the actual local power grid situation.

Subsequently, we compare each generator node *PFC* to the reference value PFC_{ref}. If the *PFC* is greater than the reference value, the generator tripping ratio can be appropriately increased by multiplying the contribution optimization coefficient; if the *PFC* is lower than the reference value, the ratio of the generator tripping is set to the standard ratio c%.

$$P_{cut}\% = \begin{cases} c\% \times \dfrac{PFC}{PFC_{ref}} & PFC > PFC_{ref} \\ c\% & PFC \leq PFC_{ref} \end{cases} \tag{5}$$

After implementing the optimization of the generator tripping ratio, it is necessary to perform an accumulated check on the tripping amount of each generator unit. If the accumulated power is greater than the maximum generator tripping capacity of the round, the tripping object of the round is just the generator unit, and the generator tripping capacity is taken as the maximum cutting capacity P_{max}.

Case Study

In this paper, a 3-machine 10-node AC/DC power grid is taken as an example to verify the proposed over-frequency generator tripping method, and the corresponding operating conditions of the test system is shown in Fig. 2.

In Fig. 2, there are three power plants with symbols A, B, and C. In addition to supplying power to the region, these power plants also transmit power to BUS-L through DC line C-L.

When the fault occurs on the outgoing DC line of BUS-C to BUS-L, if no measures are taken, not only the system frequency will rise to 51.45Hz, but also the system frequency is greater than 50.8Hz for up to 1012 cycles (20.24 s) as shown in Fig. 3.

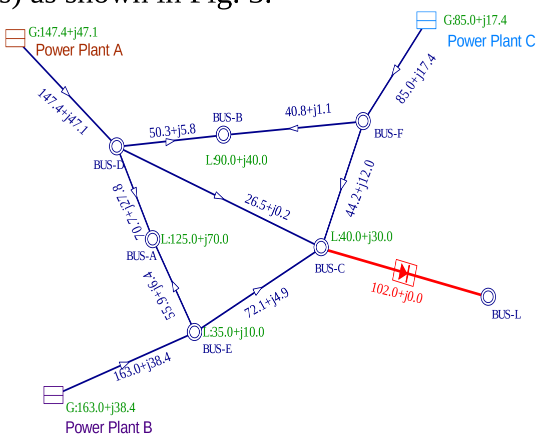

Figure 2. The geographical diagram of hybrid AC/DC system

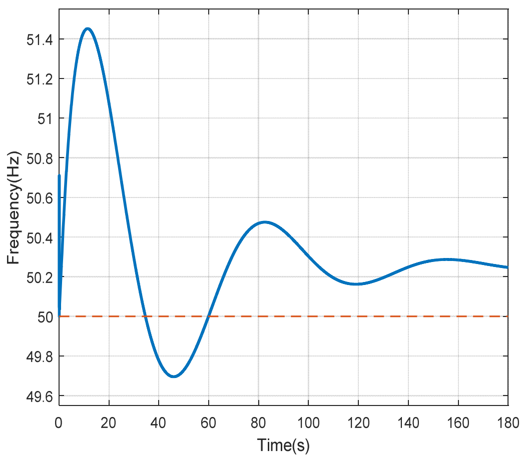

Figure 3. System frequency response without taking any measures

Here, we set 50.8Hz as the first-round operating frequency of over-frequency generator tripping, and 5% as the basic tripping capacity per round. The frequency change by applying the proposed method in this paper is shown in Fig. 4, and Fig. 5 shows the enlarged picture of the over-frequency generator tripping action selected from the over-frequency generator tripping action portion of Fig. 4.

During the fault process, the maximum frequency of the test system is only about 50.9Hz. It can be seen from Fig. 4 that the high frequency problem of the test system is effectively solved, the system frequency does not continue to deteriorate, and finally stabilizes at about 50.03Hz, thus demonstrating the effectiveness of the proposed method.

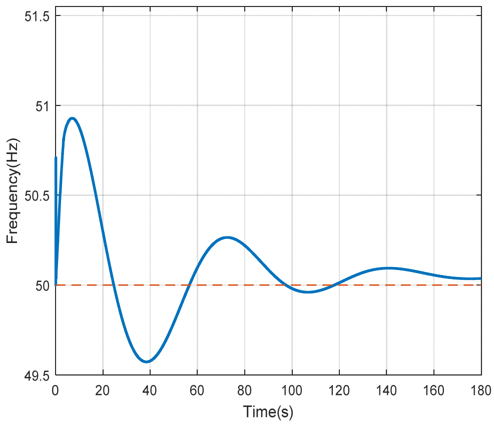

Figure 4. System frequency response using the proposed method when the same fault occurs

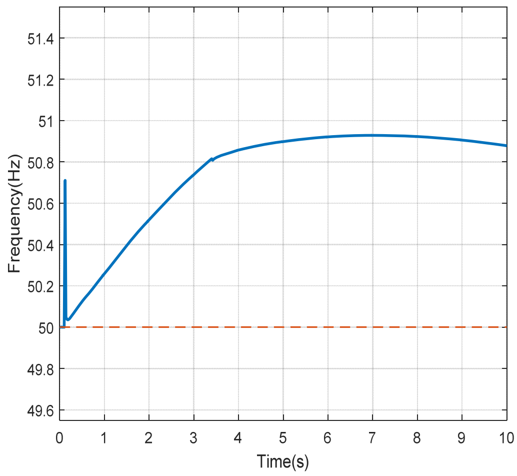

Figure 5. Partial enlargement of system response using the proposed method

Conclusion

With the continuous development of modern power grid, the frequency stability issue has gained wide attention from academic scholars and electrical engineers. Different from the traditional empirical over-frequency generator tripping scheme, this paper proposes a flexible over-frequency generator tripping scheme based on the power flow tracing technology. The maximum generator tripping capacity of each round is first determined in the preprocessing. And the power flow contribution level of each generator unit is calculated by using the power flow tracing after a line fault. Subsequently, we sort and group each power flow contribution level. In order to suppress the system frequency from increasing and accelerate the system frequency recovery, the proportion of generator tripping is optimized, and then the maximum generator tripping capacity is used to inspect over tripping phenomenon. Finally, simulation results demonstrate that the proposed method can effectively avoid the over-tripping and under-tripping problems caused by the empirical over-frequency generator tripping method.

References

[1] A. G. Endegnanew and K. Uhlen, Global analysis of frequency stability and inertia in AC systems interconnected through an HVDC. 2016 IEEE International Energy Conference (ENERGYCON), Leuven, 2016, pp. 1-6.

[2] Z. Song, Y. Lin, C. Liu, Z. Ma and L. Ding. Review on over-frequency generator tripping for frequency stability control. 2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Xi'an, 2016, pp. 2240-2243.

[3] A. S. Elansari, M. F. Edrah and S. M. Khaled. Improve transient frequency response by adjusting generators' over frequency relays. 2012 IEEE International Conference on Power and Energy (PECon), Kota Kinabalu, 2012, pp. 458-463.

[4] J. N. Bank, R. M. Gardner, J. K. Wang, A. J. Arana and Y. Liu. Generator Trip Identification Using Wide-Area Measurements and Historical Data Analysis. 2006 IEEE PES Power Systems Conference and Exposition, Atlanta, GA, 2006, pp. 1677-1681.

[5] J. Bialek. Tracing the flow of electricity. IEE Proceedings - Generation, Transmission and Distribution, 143(4), pp. 313-320, July 1996.