

응통전력 여유 향상을 위한 BTB 컨버터 제어 전략 수립

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On Control Strategies for BTB Converters for Enhancement of Interface Flow Margins

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Abstract - This paper presents a method to determine parameters of BTB (back-to-back) converters in terms of the enhancement of interface flow margins. Interface flow margin is by definition a measure of how much active power can be transferred from the external areas to the study area with the fixed load demand, and it is mainly constrained by system voltage stability. BTB converters are controllable equipments with the active power flow through them, and its DC link in fact can divide the AC systems at the location and hence can reduce the fault current level. This paper first calcs margin sensitivities at the nose point of F-V curves and formulates an optimization problem to update the BTB parameters to improve the margins. This procedure is repeated performed until the required margin enhancement is achieved.

1. Introduction

In the competitive energy markets with large scale integration of renewable energy sources, today's power systems need more controllability to transmit the increased bulk power in a secure manner. FACTS (Flexible AC Transmission Systems) and HVDC (High Voltage Direct Current) devices are drawing the attention of system planners because they can provide more flexibility so that an improvement of angular, frequency and voltage stability is achieved in system operation. BTB (back-to-back) converters are similar to HVDC systems but they do not include DC transmission lines, so the rectifiers and inverters are at the same substation. BTB converters are then usually equipped to interconnect two systems with different fundamental frequencies.

Another positive impact of equipping BTB converters is the reduction of the fault current level. Higher fault current is one of critical issues that need to be solver for heavily looped systems such as Korean power system. When BTB converters are equipped on a portion of transmission lines, it indeed does partition the AC systems at the point and hence increases equivalent impedances on locations. However, it is clear that the increase in the magnitude of the equivalent impedance may seriously deteriorate system transfer capability [1]. Thus, in decision making of the placement for BTB converters, it is needed to consider the effect of the controllability of BTB on transfer capability.

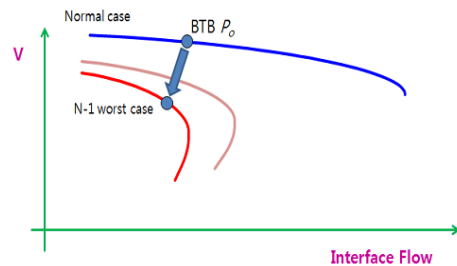
This paper presents a method for determining the setting point of BTB parameters in terms of enhancement of interface flow margins. Interface flow margins [2-3] are one of measures for the security level of power system perspectives to voltage stability. For critical cases with lower interface flow margins, sensitivities of margin enhancement [4-5] at the captured nose points are obtained using the information of zero-eigenvector of Jacobian matrix. An optimization problem constructed, in this paper, using the sensitivity information for BTB parameters to find the adequate parameter settings to enhance the interface flow margins. The determined setting

points with the optimization problems are verified by re-evaluating the interface flow margins. The procedures are repeatedly performed until the desired margin enhancement is achieved.

2. Review of Interface Flow Margins

For secure operation, transfer capability of the system needs to be identified. Voltage stability is one of critical factors that actually limit transfer capability. In the procedure for determining transfer capability, a certain scenario needs to be pre-defined, and the usually used scenario is to increase the load demand in the sink and to increase almost the same amount of generation in the source. This scenario can be more applicable to the interconnected systems including several power pools because there are several transfer directions that can happen. In cases where the system is operated by one system operating body, it is more desirable to evaluate transfer capability through the interface lines connecting the load center and the external area with the fixed load demand because the transfer limit can be directly available for the system with the corresponding load level. Another scenario to increase the interface flow without varying the load level is to decrease the generation in the load center and to increase that in the external regions.

In [2], the formulation of the modified continuation power flow (MCPF) was proposed, incorporating the second scenario into the power flow equations. Using the tool, F-V curves as in Fig. 1 can be constructed and with them interface flow margins, which is by definition how much active power can be more transferred through the interface lines, can be evaluated for their corresponding states. Like other voltage stability indices, the minimum requirement of the margin needs to be given in the system operation guide lines.

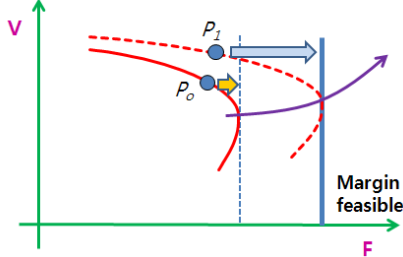


<Fig. 1> F-V Curves with the normal and N-1 contingent cases

3. Parameter Determination for BTB Converters

As in Fig. 1, assume that active power injection through a BTB converter is set to  $P_o$  in the systems. When applying one of N-1 worst contingencies, however, if the interface flow margin is much lower than the required margin, then a

certain set of controls need to be applied, considering further events seriously deteriorating the system security. For the purpose, this paper mainly considers parameters of the BTB itself as control means such as active power injection through BTB and shunt susceptances of BTB's neighboring buses if available. Fig. 2 illustrates the case where active power injection setting is changed from  $P_o$  to  $P_l$  to enhance the margin until it satisfies the minimum requirement.



<Fig. 1> Margin enhancement by the change of BTB active power injection

### 2.1 Margin Enhancement Sensitivity

This paper basically adopts the margin enhancement sensitivities at the nose point in the procedure for determining controls of BTB parameters. When applying a continuation method to evaluate the margin, a system parameter should be defined, and for MCPF to construct F-V curves the system parameter represents the generation shifting direction from the load center to the external regions. The reformulated power flow equations with the system parameter,  $\mu$ , can be briefly explained as follows:

$$f(x, p, \mu) = 0 \quad (1)$$

where  $x$  denotes the state vector for bus voltage magnitudes and angles and  $p$  is a control parameter.

At the nose point of an F-V curve, margin enhancement sensitivities with respect to control parameters can be obtained. Applying the chain rule at the point yields:

$$f_x dx + f_p dp + f_\mu d\mu = 0 \quad (2)$$

where  $[dx \ dp \ d\mu]^T$  is the tangent vector from the solution and  $f_x$ ,  $f_p$  and  $f_\mu$  represent Jacobian matrices with respect to  $x$ ,  $p$  and  $\mu$ , respectively. At the nose point, the determinant of  $f_x$  is 0, so there is a zero eigenvalue with  $f_x$ . By pre-multiplying the left zero-eigenvector,  $v^T$ , the first term of (2) is eliminated, and then the margin enhancement sensitivity with respect to  $p$  can be obtained as follows:

$$S_p = -F_o \frac{dv}{dp} = -F_o \left( \frac{v^T f_p}{v^T f_\mu} \right) \quad (3)$$

where  $F_o$  is the initial interface flow at the base case.

### 2.2 Application of QP

Using the margin enhancement sensitivities obtained at the nose point, this paper iteratively performs a quadratic programming optimization until the required margin is satisfied. Using the QP, each parameter's correction is solved and its impact is verified by the re-evaluation of the interface flow margin for the contingent case.

The optimization problem can be expressed as follows:

$$\begin{aligned} \min & \sum_{i=1}^{N_{BTB}} w_{P_i} \Delta P_{BTB_i}^2 + \sum_{k=1}^{N_{BSH}} w_{B_k} \Delta B_{SHk}^2 \\ \text{s.t.} & \sum_{i=1}^{N_{BTB}} S_{P_i} \Delta P_{BTB_i} + \sum_{k=1}^{N_{BSH}} S_{B_k} (\Delta B_{SHk}) \geq \alpha \Delta P_{mrg} \\ & \Delta P_{BTB_i}^{\min} \leq \Delta P_{BTB_i} \leq \Delta P_{BTB_i}^{\max}, i=1, \dots, N_{BTB} \\ & \Delta B_{SHk}^{\min} \leq \Delta B_{SHk} \leq \Delta B_{SHk}^{\max}, k=1, \dots, N_{BSH} \end{aligned} \quad (3)$$

where  $\Delta P_{BTB_i}$  and  $\Delta B_{SHk}$  are the correction of the active power injection for the  $i$ -th BTB converter and the  $k$ -th

shunt susceptance, respectively, and  $N_{BTB}$  and  $N_{BSH}$  denote the number of BTB converters and controllable shunt susceptances. In (3),  $w_{P_i}$  and  $w_{B_k}$  are weighting factors for  $\Delta P_{BTB_i}$  and  $\Delta B_{SHk}$ ;  $S_{P_i}$  and  $S_{B_k}$  stand for the margin sensitivities with respect to  $\Delta P_{BTB_i}$  and  $\Delta B_{SHk}$ ;  $\Delta P_{mrg}$  and  $\alpha$  represent the required margin enhancement and the accelerating factor;  $\Delta P_{BTB_i}^{\min}$  and  $\Delta P_{BTB_i}^{\max}$  are the lower and upper limits for  $\Delta P_{BTB_i}$ ;  $\Delta B_{SHk}^{\min}$  and  $\Delta B_{SHk}^{\max}$  are the lower and upper limits for  $\Delta B_{SHk}$ .

## 3. Results

This paper applied the proposed method to '17 KEPCO system at peak load. To evaluate interface flow margins for the normal and contingent cases of interest for the system with BTB converters, a simplified model for BTB converters was implemented to MCPF. In this study, 9 selected contingencies are mainly considered for the evaluation of interface flow margins. It is assumed that four line-commutated BTB converters are equipped at the selected positions of the system, and that active power injections for the two BTBs are set to 100 MW and shunt susceptances at the neighboring buses compensate their reactive power consumption by the converters. The results will show that the required margin at the worst N-1 contingency case can be achieved by the parameters of the BTB converters with the proposed method.

## 4. Conclusions

This paper presents a method for determining optimal parameter settings for BTB converters in terms of interface flow margins. BTB converters are to mainly control the active power flow through them and they are to reduce the fault current level by dividing the AC systems at the installed location. Perspective to transfer capability, adequate control on BTB parameters need to be established. For BTB parameter setting in terms of interface flow margins, this paper calculates margin enhancement sensitivities at the nose point of F-V curves using MCPF including a simplified BTB model and applies a QP optimization problem successively to find the update of BTB parameters to improve the margins until satisfying the margin criterion.

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