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Calculation of Active Power Transfer Capability using Repeated Power Flow Program

Jung-Pil Ham, Byung-Ha Lee, Jung-Hoon Kim and Jong-Ryul Won

Abstract - The power transfer capability is determined by the thermal, dynamic stability and voltage limits of the generation and transmission systems. The voltage stability depends on the reactive power limit and it affects the power transfer capability to a great extent. Then, in most load flow analysis, the reactive power limit is assumed as fixed, relatively different from the actual case. This paper proposes a method for determining the power transfer capability from a static voltage stability point of view using the IPLAN which is a high level language used with PSS/E program. The f-V curve for determining the power transfer capability is determined using Repeated Power Flow method. It is assumed that the loads are constant and the generation powers change according to the merit order. The maximum reactive power limits are considered as varying similarly with the actual case and the effects of the varied maximum reactive power limits to the maximum power transfer capability are analyzed using a 5-bus power system and a 19-bus practical power system.

Keywords – power transfer capability, Repeated Pouer Flow Bethod, voltage stability

1. Introduction

Restructuring of KEPCO(Korea Electric Power Corporation) causes that the monopolistic company is divided into several companies and the inter-area power transfer is highlighted as a key issue. Furthermore, the exact evaluation of the maximum power transfer capability is required as transmission systems become more stressed and complicated. Many researchers have studied the inter- change capability of power systems as limited by the generation and transmission systems. Linear programming, linear DC power flow, and distribution factors were applied to determine capabilities based on thermal and voltage limits[1,2]. It was shown that the interchange capability is additionally determined by dynamic stability limits via an energy margin calculation [3]. In [4], the real power transfer capability of a large scale power system was determined using the simulation tool CPFLOW. A simple, efficient, and non-iterative method was proposed in order to compute the ATC between any two locations in the transmission system and ATC's for any selected transmission paths between them[5]. The power transfer capability is limited by the thermal, dynamic stability and voltage stability of the generation and transmission systems. The voltage stability depends on the reactive power limit and it affects the power transfer capability to a great extent. Then, in most load flow analysis, the reactive power limit is assumed as fixed, considerably different from the actual case.

In this paper, the authors employ a method for determining the power transfer capability using the IPLAN which is a high level language used with PSS/E program.

The maximum reactive power limits are considered as varying similarly with the actual case. The effects of the varying maximum reactive power limits to the voltage stability and the maximum power transfer capability are analyzed under varying generation.

The approximate nose point is determined by Repeated Power Flow Method using the simulation tool, which is developed with IPLAN. It is assumed that the loads are constant and the generation powers change according to the merit order which the KEPCO utilizes for economic dispatch. A 2 generator 5 bus system and a 7 generator 19 bus practical system of the Ul-lung island are used to illustrate the effect of the varying maximum reactive power limits to voltage stability and the maximum power transfer capability. The case when the reactive power limit is considered as varied and the case when the reactive power limit is considered as fixed, are analyzed. The evaluations of the voltage collapse and the maximum power transfer capability of these test power systems are performed according to each case and compared to each other.

2. Method of Voltage Stability Assessment Based on Power Flow

2.1 Continuation Power Flow (CPF)

For a steady state power system, the load flow equation can be written as follows. [6]

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$$f(x,\lambda) = F(x) + \lambda b = 0 \tag{1}$$

where

x: the n-vector of state variables

λ : a parameter used to represent the change in demand or generation at all buses.

b : the direction vector representing the changes P,Q in generation and load.

If the load is increased following a certain pattern from the initial value, λ_0, the f-Vcurve (line flow-voltage curve) shown in Fig. 1 can be obtained by using CPF method. When the load is increased, the voltage at a bus or collective buses will decrease. At the extreme condition, a maximum power transfer limit is reached at the collapse point λ^*. The margin to voltage collapse is defined as the largest load change that the power system may sustain from a well defined operating point. The continuation power flow is an iterative process which is divided into two steps: predictor and corrector. In the predictor step, linear approximation is used to predict the next solution for a change in one of the state variables. This solution will be used as the initial condition for the second step. In the corrector step, the approximate solution is corrected by using a parameterization scheme. The parameterization scheme provides a means of identifying each point along the solution path and plays an integral part in avoiding singularity in the Jacobian.

As λ varies from λ_0 to λ^*, the f-V curve shown in Fig.1 can be obtained by CPF algorithm.

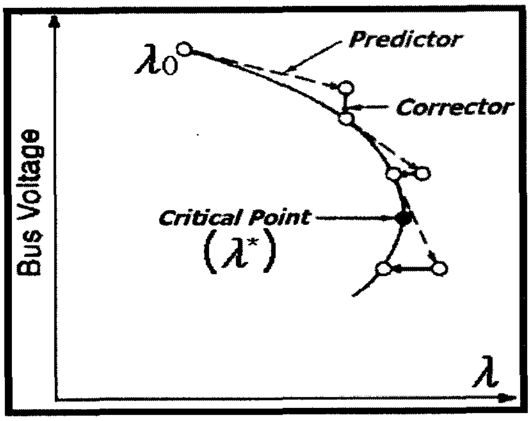

Fig. 1 An illustration of the continuation power flow

2.2 Generalized Curve Fit

This method estimates the voltage collapse point using a curve fitting technique. The stable branch of the P-V(power-voltage) or f-V curve (top portion) can be approximated by a second order polynomial. Three points on the stable branch of P-V or f-V curve are sufficient to determine the polynomial's coefficients. The first point can be obtained from the data on the current operating condition. Other two points can be computed by increasing the load demand. The third point should be selected to be closer to the nose point for better curve estimation. Once the 3 coefficients of the polynomial are computed, the approximate P-V or f-V curve is determined and the approximate voltage collapse point is obtained. An example of the generalized curve fit method is shown in Fig. 2. The farther the distance between the collapse point and third point (T_3 in Fig. 2), the bigger the error. The accuracy of this method depends on the location of the 3 selected points.

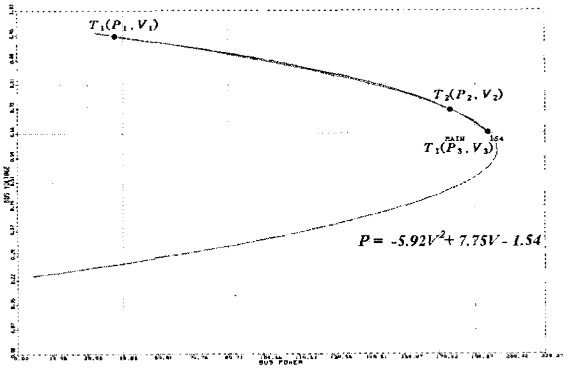

Fig. 2 Generalized curve fit algorithm.

2.3 Repeated Power Flow

Repeated power flow method is a method to obtain P-V or f-V curve by calculating power flow solutions repeatedly with the common power flow package until they are not solved. The load is increased according to a specific scenario and power flow is solved for each changed condition. The flowchart of the repeated power flow method is shown in Fig. 3. The approximate voltage collapse point can be also obtained by this method.

The nose points of P-V or f-V curves can be calculated by CPF, GCF and RPF methods. CPF can determine the correct voltage collapse point under the condition that the generation powers of all the generators change evenly, but it has considerable error because the generation powers of all the generators change uniformly with changing the parameter λ and this condition is very different from the practical generation power variation. GCF and bisection method can reduce the iteration number of power flow calculations, but their results can be greatly different from the exact value according to the points selected to derive an approximate curve. RPF method utilizes the public power system analysis program PSS/E used to derive the P-V curve and f-V curve and so the accuracy of the simulation results are guaranteed. Also, in this method the generation powers of all the generators can be changed according to the merit order, which is the priority order that KEPCO utilizes for economic operation. Therefore, the results are almost consistent with the practical case.

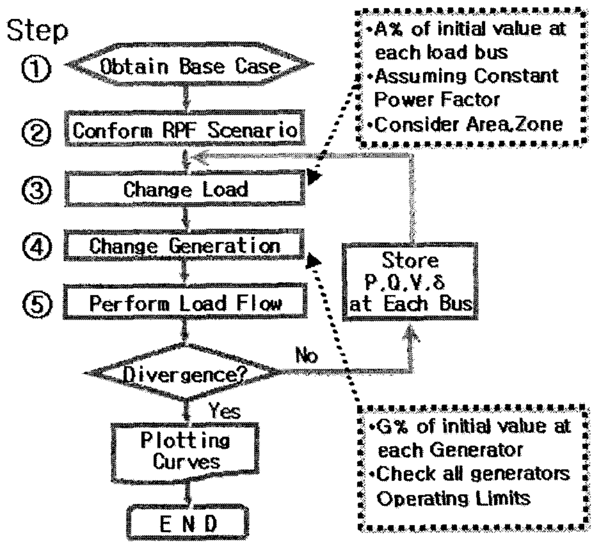

Fig. 3 The Flow-Chart of Repeat Power Flow

3. The Reactive Power Limit of the Generator

The voltage stability depends on the reactive power limit and it affects the power transfer capability to a great extent. In conventional load flow algorithm, the reactive power limit of the generator is considered as fixed, but it changes considerably as the real power varies. The reactive power limit used in most load flow analysis illustrated in Fig. 4.

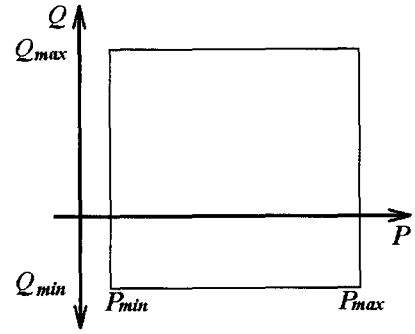

Fig. 4 Simplified generator operating limits

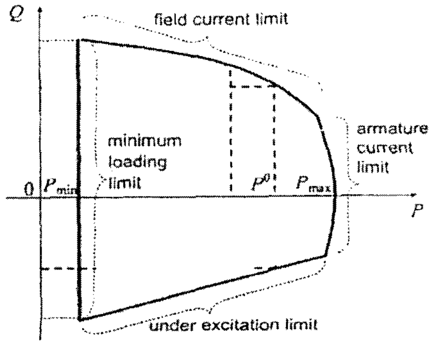

Fig. 5 Real generator operating limits

An example of actual generator operating limits are shown in Fig. 5. The varied reactive power limits should be con sidered for the more accurate analysis of voltage stability. [7] Here, the curve of reactive power limit is divided into two parts, which are approximated as two curves of secondary degree. The execution burden of power flow calculation is almost similar to the case where the reactive power limits are considered as fixed.

4. Case Study

An repeated power flow method is applied to obtain P-V or f-V curve and the varied maximum reactive power limits are considered for voltage stability analysis. A tool to calculate power flow solutions by the repeated power flow method is developed using IPLAN language. The IPLAN program makes the efficient running of PSS/E package available. The repeated power flow calculations are performed automatically by the developed IPLAN program. Two power systems are analyzed under the varied maximum reactive power limits. A 2 generator 5 bus test system and a 7 generator 19 bus test system are used for analysis. A 2 generator 5 bus test system is shown in Fig. 6.

The repeated power flow method is applied increasing the each load by 5 % per step. The P-V curves of 300, 400 and 500 buses are shown in Fig. 7. The left curve is the simulation result when the reactive power limit is considered as varied and the right one the simulation result when the reactive power limit is considered as fixed. The values of approximate nose points in the P-V curves are listed in Table 1. It is shown that the varied maximum reactive power limits cause the more severe effects on voltage stability. Fig 8 shows that the reactive power outputs of the generator 200 bus according to each case vary differently as load increases. The triangle symbols curve is the trajectory of the reactive power output with the maximum reactive power limit fixed. The square symbols curve is the trajectory of the reactive power output with the maximum reactive power limit varied. The solid line curve and the cross symbols curve show the varied maximum reactive power limit and the fixed maximum reactive power limit, respectively.

A 7 generator 19 bus practical system of the Ullung-island is shown in Fig. 9. This system is divided into two areas, that is, area I and area II.

The scenario is as follows:

- All loads of area I and area II are constant.
- Area I generation decreases step by step until the solution of the power flow diverges.
- Area II generation increases step by step until the solution of the power flow diverges.

Similarly the repeated power flow method is applied varying each generation according to the scenario. The f-V curves of 400, 700 and 800 buses are shown in Fig. 10. The left curve is the simulation result when the reactive power limit is considered as varied and the right one the result when the reactive power limit is considered as fixed. The values of approximate nose points in the f-V curves and the number of repeated power flow calculation are listed in Table 2. In this case it is also shown that the varied maximum reactive power limits cause the more severe effects on the maximum power transfer capability.

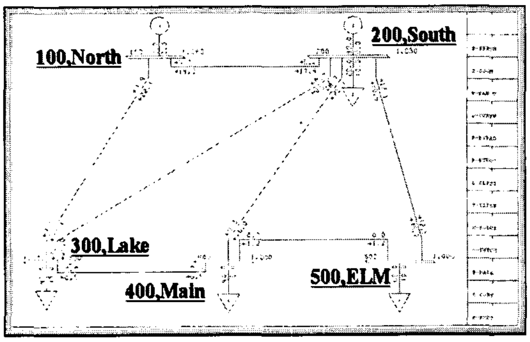

Fig. 6 5 bus Sample system

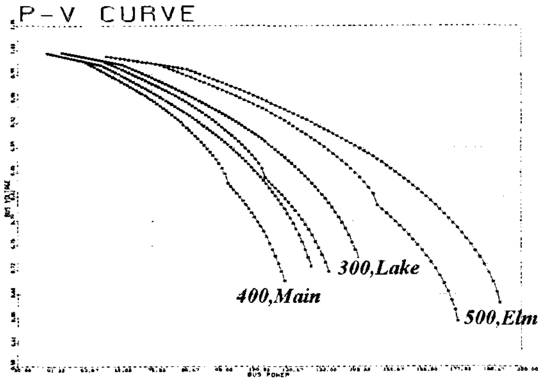

Fig. 7 Effects of varied Qmax to load buses(300,400,500)

Table 1 Effects of Varied Qmax in 5 bus real system

	300, Lake		400, Main		500, Elm	
	P	V	P	V	P	V
Fixed Qmax	145.00	0.732	129.00	0.722	192.70	0.672
Varied Qmax	135.00	0.714	120.00	0.701	178.46	0.647

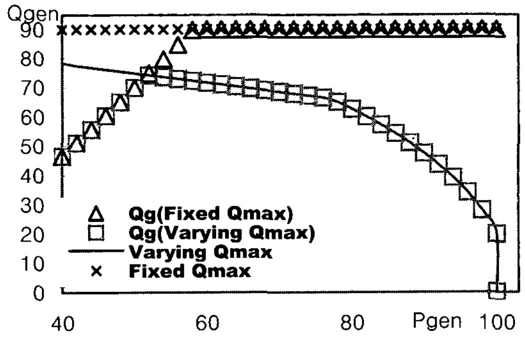

Fig. 8 The reactive power outputs of the generator 200 bus according to each case

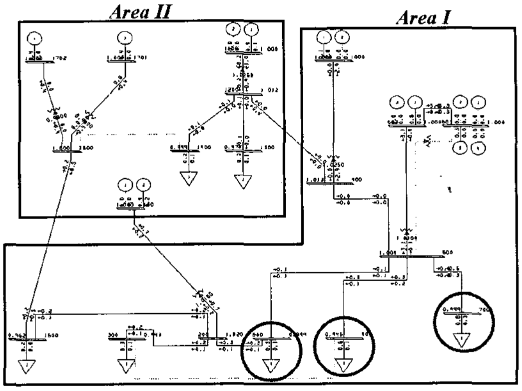

Fig. 9 19 Bus real system

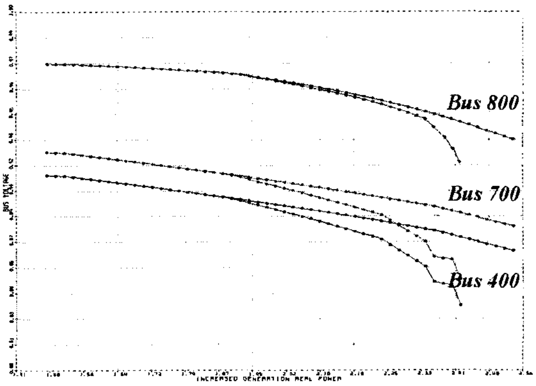

Fig. 10 f-V Curves in 19 bus system (bus 400,700,800)

Table 2 Effect of Varied Qmax in 19 bus real system

	Max Power Transfer	Iteration	Voltage		
			400	700	800
Fixed Qmax	2.558	58	0.911	0.923	0.929
Varied Qmax	2.438	51	0.853	0.867	0.931

* All values are [P.U]

5. Conclusions

The effects of the varied maximum reactive power limits to the voltage stability and the maximum power transfer capability are analyzed under varying generation. The nose point is determined approximately by Repeated Power Flow Method using the simulation tool, which is developed with IPLAN. It is assumed that the generation powers change according to the merit order which the KEPCO utilizes for economic dispatch. A 2 generator 5 bus system and a 7 generator 19 bus practical system are used to illustrate the effect of the varying maximum reactive power limits to voltage stability and the maximum power transfer capability. The case when the reactive power limit is considered as varying and the case when the reactive power limit is considered as fixed, are analyzed. The evaluations of the voltage collapse and the maximum power transfer capability of these power systems are performed according to each case and compared to each other. It is shown that the varying maximum reactive power limits of the generator may cause the more severe effects on voltage stability and the maximum power transfer capability.

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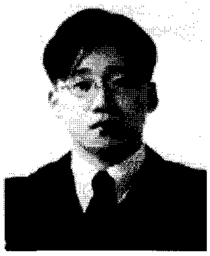

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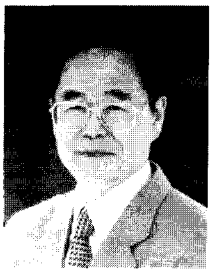

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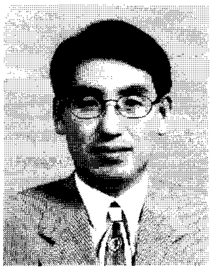

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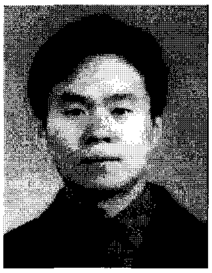

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