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Optimization for Minimum Switching Operation of STATCOM, External Bank, Tap Changer using ILP

Chang Han Ahn *, Ji Ho Park *, Geun Joon Lee ** and Young Sik Baek †

Abstract – This paper proposes a method for solving running cost problem by minimizing switching shunt element devices. The solution of the problem is approached by utilizing optimization method which optimizes shunt element devices and running costs while satisfying voltage stability index. The main contribution of this paper is to provide linear optimization solution which determining the minimizing amount of reactive power capacity commits in once respects a voltage stabilization. Moreover, the method is able to contributes in voltage stabilization the accident at the time of with the dosage commitment which is quick escapes from a sequential control method of existing. This paper suggests optimal coordinative control method between STATCOM and other reactive power controllers in substation (Shunt Reactors/Capacitors and OLTC). Therefore, it is valuable for decision maker in determining order and capacity of devices which gaining a voltage stabilization. The proposed control method selects proper device of respective control characteristic by detecting voltage error and integrated voltage error. We start by showing how to solve systems of linear equations using the language of pivots and tableaus. The effectiveness of this technique is demonstrated in modified PSS/E MIGUM 45 bus system. The simulation results show the effectiveness of this algorithm by comparing the outcome with several established methods.

Keywords: Minimum switching, Optimization, Statcom, Shunt element devices, ILP

1. Introduction

Due to the market participants' understanding and their direct associations, so far the management issues concerning active power such as the periodic supply and demand plans as well as the reserve standards have been managed systematically. In contrast, the maintenance of reactive power has not been managed systematically, because of its regional specificity and local factors. At the moment, the problems with the shunt elements plans are carried out through power flows using the anachronistic method which relies on the experience and knowledge of the system operators. Such method requires much time, and also it is difficult to present a economically optimized result for the system. Therefore, reactive power is in need of a more systematic and efficient plan. The close/break plan of the shunt elements applied with the optimization method concerns a optimal load flow calculation that includes discrete variables and it also determines the making capacity and timing, while contributes to the system economically by allowing minimum number of switching. In this thesis, the optimization algorithm was applied for minimizing number of switching for the shunt elements and for setting the objective functions and constraint variables by integerizing the switchable shunt elements. Moreover, ILP was applied in order to obtain a solution and to confirm validity of the solution, and then it was compared with the existing sequence control method (Back-to-Back method).,

2. Configulation of Optimization Problem and Fomulation

2.1 Objective Function

In order to solve the making problems with the phase modifying equipment, minimization of making the shunt elements has been set as the objective function. In addition, as the system should satisfy an appropriate driving range under normal conditions as well ascontingency, sensitivity of bus voltage and reference STATCOM voltage have been included to satisfy the system's driving range.

The objective function represents the switching conditions and numbers of reactor (L), capacitor (C), and tab (T).

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† Corresponding Author: Dept. of Electrical Engineering, Kyungpook National University, Korea.(ysbaek@knu.ac.kr)

* Dept. of Electrical Engineering, Kyungpook National University, Korea (achjjang@nate.com)

** Dept. of Electrical Engineering, Chungbuk Provicial College, Korea (gjlee@ctech.ac.kr)

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Furthermore, L0, C0, and T0 indicate the initial switching conditions, while CL, CC, and CT indicate the weight in the objective function resulted from the relative costs caused by making of each equipment.

$$\min f = C_L\{\sum_{i=1}^{L_0} iL_i + \sum_{i=1}^{5-L_0} iL_{(i+L_0)}\} + C_C\{\sum_{j=1}^{6-C_0} jC_j + \sum_{j=1}^{C_0} jC_{(6-C_0+j)}\} + C_T\{\sum_{k=1}^{17-T_0} kT_k + \sum_{k=1}^{T_0} kT_{(k+17-T_0)}\}$$

$$\begin{aligned} s.t \quad & \sum_{i=1}^{5} L_i \le 1 && L_i = 0 \ or \ 1 \ (i = 1,2,3,4,5) \\ & \sum_{j=1}^{6} C_j \le 1 && C_j = 0 \ or \ 1 \ (i = 1,2,3,4,5,6) \\ & \sum_{k=1}^{17} T_k \le 1 && T_k = 0 \ or \ 1 \ (k = 1,2,3,\ldots,17) \end{aligned}$$

$$\begin{aligned} & 0.0052\{\sum_{i=1}^{L_0} iL_i - \sum_{i=1}^{5-L_0} iL_{(i+L_0)}\} \\ & + 0.0024\{\sum_{j=1}^{6-C_0} jC_j - \sum_{j=1}^{C_0} jC_{(6-C_0+j)}\} \\ & + 0.0008\{\sum_{k=1}^{17-T_0} kT_k - \sum_{k=1}^{T_0} kT_{(k+17-T_0)}\} \\ & \qquad \le V_{1s} - V_1^m - \Delta V_1^{statcom} \end{aligned}$$

$$\begin{aligned} & 0.0048\{\sum_{i=1}^{L_0} iL_i - \sum_{i=1}^{5-L_0} iL_{(i+L_0)}\} \\ & + 0.0052\{\sum_{j=1}^{6-C_0} jC_j - \sum_{j=1}^{C_0} jC_{(6-C_0+j)}\} \\ & + 0.011\{\sum_{k=1}^{17-T_0} kT_k - \sum_{k=1}^{T_0} kT_{(k+17-T_0)}\} \\ & \qquad \le V_{2s} - V_2^m - \Delta V_2^{statcom} \end{aligned}$$

The binary integer was used for the constraint variables to limit the number of application of each equipment.

In addition, switching was determined according to the voltage error by measuring sensitivity of each equipment. As the Optimization Algorithm does not directly deal with the discrete variables, linear variable was applied according to the closing/breaking capacity of the phase modifying equipment. Here, the constraint variables were designed in considering the characteristic of STATCOM that only affect the initial voltage control, but they do not influence closing and breaking of the phase modifying equipment.

3. Optimization Algorithm

3.1 Linear programming relaxation

The LP obtained by deleting the constraints x ∈ Z^n (or x ∈ $\{0, 1\}^n$) is called the LP relaxation.

step1 Provides a lower bound on the optimal value of the integer LP

step2 If the solution of the relaxation has integer components solves the integer LP

step3 Equivalent ILP formulations of the same problem can have different relaxations

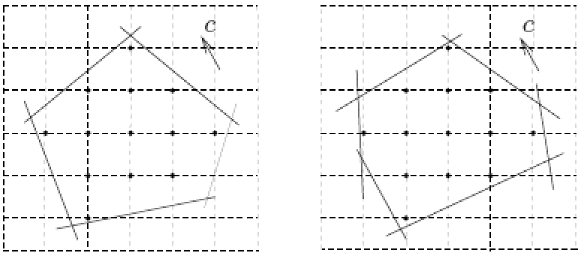

Fig. 1. Equivalent ILP formulations.

The convex hull of the feasible set S of an ILP is:

$$convS = \{\sum_{i=1}^{K} \lambda_i x^i \,\big|\, x^i \in S, \lambda_i \ge 0, \sum_i \lambda_i = 1\}$$

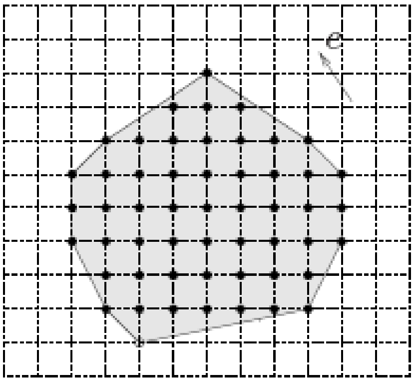

Fig. 2. The smallest polyhedron containing S.

for any c, the solution of the ILP also solves the relaxation
minimize $c^T x$
subject to x∈ conv S

3.2 Branch-and-bound algorithm

minimize $c^T x$
subject to x∈ P_i
where P_i _ P, i = 1, . . . ,K

step1 To solve subproblem: decompose recursively in smaller problems

step2 Use lower bounds from LP relaxation to identify subproblems that don't lead to a solution

where c = (−2,−3, 0), and

$$P = \{x \in Z_+^{\;3} \,|\, x_n \le 1,\ \frac{dV}{dL}x_1 + \frac{dV}{dC}x_2 + \frac{dV}{dT}x_3 \le \Delta V\}$$

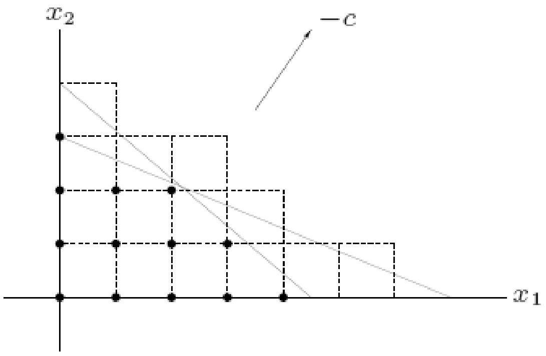

Fig. 3. Optimal point.

s.t $x \in \{0, 1\}^n$

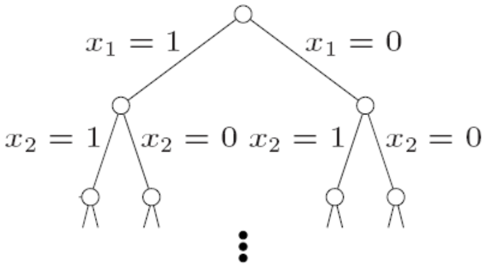

Fig. 4. Branch-and-Bound for 0-1 linear program.

can solve by enumerating all 2^n possible x; every node represents a problem

minimize c^Tx
subject to $Ax \le b$
$x_i = 0,\ i \in I_1,\quad x_i = 1,\ i \in I_2$
$x_i \in \{0, 1\},\ i \in I_3$
where I_1, I_2, I_3 partition $\{1, \ldots, n\}$

set U = +1, mark all nodes in the tree as active
step1 select an active node k, and solve the corresponding LP relaxation

$$\begin{aligned} \text{minimize}\quad & c^Tx \\ \text{subject to}\quad & Ax \le b \\ & x_i = 0,\ i \in I_1^k \\ & x_i = 1,\ i \in I_2^k \\ & 0 \in x_i \in 1,\ i \in I_3^k \end{aligned}$$

let $\vec{x}$ be the solution of the relaxation

step2 if $c^T\vec{x} \ge U$, mark all nodes in the subtree with root k as inactive

step3 if all components of $\vec{x}$ are 0 or 1, mark all nodes in the subtree with root k as inactive; if moreover $c^T\vec{x} < U$, then set $U = c^T\vec{x}$ and save $\vec{x}$ as the best feasible point found so far

step4 otherwise, mark node k as inactive

step5 go to step 1

4. Simulation Result

In order to confirm validity of the optimization solution, the switching result that used the sequence control method, which is the existing control method, was compared with the result obtained by using the optimization control method that this thesis proposes.

4.1 Results of Application of Back-to-Back Control Algorithm

The Back-to-Back Control Algorithm uses a sequence control method. Once a primary (345KV) voltage control is completed at Migum substation, a secondary (154KV) voltage control begins. Making capacity is determined by the locations of the equipment, and making process is done one by one. The optimization algorithm is programmed in the Intouch HMI Software, and the power flow is calculated using the PSS/E..

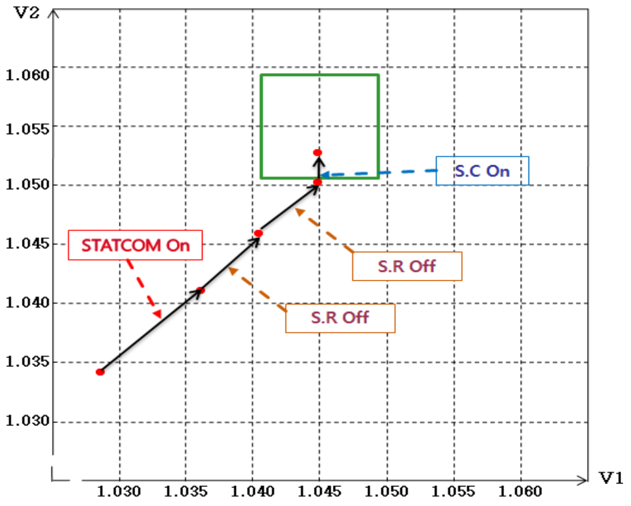

Fig. 5. Results of Application of Back-to-Back Control

Fig. 5 shows the making order and number of equipmentneeded for controlling voltage up to the standard voltage, when the initial voltage(V1:1.0275, V2:1.0340) was provided.

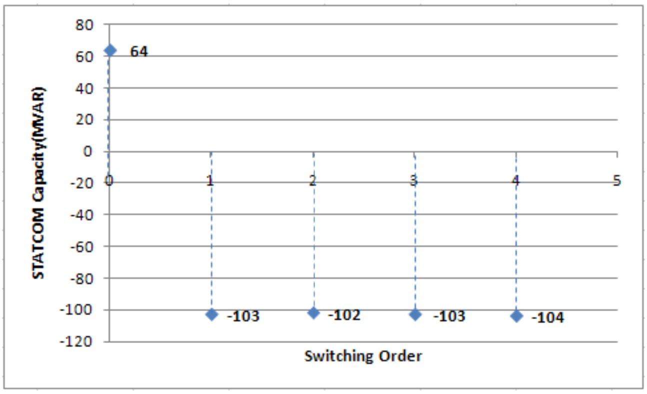

Fig. 6. Changes in STATCOM capacity by switching shunt elements.

Fig. 6 contains the data that show the reactive power changes with STATCOM upon closing/breaking of the phase modifying equipment, and the evidence that support validity of the linear objective functions and the constraint variables.

4.2 Results of Application of Optimization Control Algorithm

The Optimization Control Algorithm was applied under the same initial condition as the Back-to-Back Control Algorithm, In order to obtain a solution for the objective functions, a simulation was performed by using Matlab.

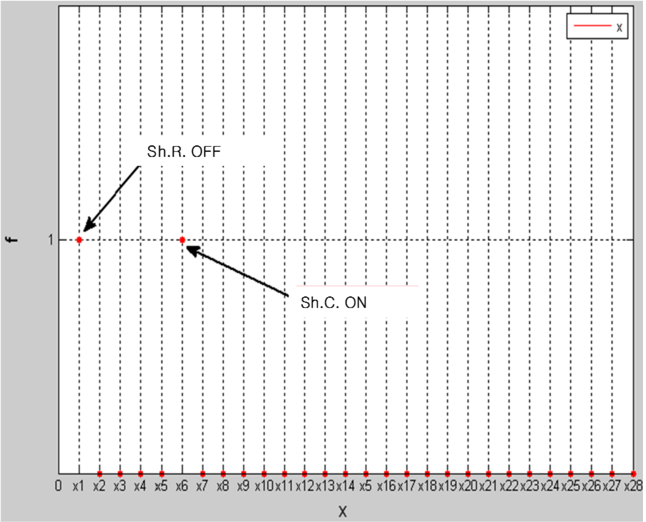

Fig. 7. Results of Application of Optimization Control Algorithm.

In Fig. 7, the value at x1 and x6 is 1, whereas the rest of variables are 0. 1 at x1 means breaking of one reactor. 1 at x6 means making of one capacitor. With this, under the same initial conditions, it is confirmed that the switching number was reduced with the application of the Optimization Control Algorithm technique. To confirm validity of the objective functions, an analysis was carried out in comparison with the case of the application of the Back-to-Back Control Algorithm under diverse conditions.

4.3 Analysis of Results

To confirm validity of the objective functions, an analysis was carried out in terms of switching number required to control voltage, in comparison with the case of the application of the two Algorithms under diverse conditions.

Table 1. Results of switching with utilization of load

LOAD	Back-to-Back			OPTIMIZATION		
	Sh.R	Sh.C	OLTC	Sh.R	Sh.C	OLTC
60%	3	2	0	3	1	0
70%	3	3	0	2	2	0
80%	4	0	0	3	0	0
90%	0	6	1	0	6	0
100%	2	4	1	2	3	0

Table 1 shows the switching number required to control voltage in accordance with the changes in the load factor. It is visible that the making number is reduced once the Optimization Algorithm was applied.

Table 2. Results of switching with voltage difference

Voltage Difference	Back-to-Back			OPTIMIZATION		
	Sh.R	Sh.C	OLTC	Sh.R	Sh.C	OLTC
V1↑ V2↑	2	2	0	2	1	0
V1↓ V2↓	2	1	0	1	1	0

Table 2 is the results of voltage control in accordance with the variation between the primary and secondary voltage, and the standard voltage. It is evident that the making number is reduced once the Optimization Algorithm was applied.

Table 3. Results of switching control with fault.

Fault	Back-to-Back			OPTIMIZATION		
	Sh.R	Sh.C	OLTC	Sh.R	Sh.C	OLTC
LINE	2	0	0	2	0	0
TR	0	0	0	0	0	0

Table 3 represents the situation where the equipment was used in case of accident. The Optimization Algorithm and the existing algorithm have shown the same result. It is because the voltage error was minor when the line fault occurred, and hence it was possible to control it by using only two reactors.

Out of three transformers connected at Migum's primary and secondary, when one transformer was out of order, the other two transformers divided the role, and therefore there was no change in voltage.

5. Conclusion

In this study, the optimization method was introduced in establishing a plan for making of reactive power compensator. The objective of this study is to minimize number switching by comparing the voltage control results obtained with applications of the existing sequence control method and with the Optimization Algorithm. The result proves that the closing/breaking numbers of the shunt elements were reduced, and this will further realize the economic benefits of the system. For optimization, the method of integerizing the result values that are actually makeable by each capacitor bank unit was chosen. To obtain a solution, the Linear programming relaxation and the Branch-and-Bound technique were used. The 2010 Migum PSS/E Data was cited for the case study.

There is a need for a further study on development of a unified system that connects the Intouch-PSS/E-C++ founded upon the Optimization Algorithm.

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Chang Han Ahn was born in korea, on February 12, 1980. He received the B.S. and M.S. degrees from Kyungpook National University, Korea in 2009 and 2011. He is now pursuing his Ph.D. degree at Kyungpook National University. His research interest is smartgrid.

Ji Ho Park (Non-member) was born in Daegu, South Korea, on September 14, 1967. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Kyungpook National University, Daegu, South Korea, in 1991, 1996, and 2001, respectively. He is currently a Contract Professor in the School of Electrical Engineering & Computer Science, Kyungpook National University, Daegu, South Korea. His research interests are large-scale software development and transient stability simulation in power systems.

Geun-Joon Lee (SM'01) received the M.S. and Ph.D. degrees in electrical engineering from Seoul National University, Seoul, Korea, and Ulsan University, Ulsan, Korea. Currently, he is a Professor of Electrical Engineering at the Chungbuk Provincial University, Chungbuk, Korea. He has experience in the Power System Department of the Korea Electric Power Research Institute and the Energy System Research Center at the University of Texas at Arlington. His research interests include power system stability, voltage and reactive power control, FACTS, and power quality.

Young Sik Baek was born in korea, on July 8, 1950. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Seoul National University, Korea in 1974, 1979, and 1984. From 1979 to 1985, he was a Lecturer at Myungji University. He is currently a Professor in the School of Electrical and Electronic Engineering, Kyungpook National University, Daegu, South Korea. His areas of research are power system operation and control.