

A Proper Location FACTS Device Placement and Primary Generation Response Definition for Multi-Lines Buses Security Enhancement Under Contingency Analysis

Chaisit WANNOL, Supattarachai JITCHOPJAI, Narumon WANNOL,
S. BUNJONGJIT and Chai / Chow CHOMPOO-INWAI
Electrical Engineering Department, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang,
Bangkok, THAILAND

Abstract

This paper presents a proper location of FACTS device placement and a primary generation response definition for Multi-Lines buses security enhancement under contingency condition using power flow sensitivity analysis. The newly proposed scheme of optimal location FACTS device focuses on multi-lines critical voltage buses. The study uses a continuation repeat power flow technique to find the critical voltage buses in system. The Multi-Lines bus security assessment has considered Available Transfer Capability of transmission lines connected to bus. The FACTS device in this paper will focus on installing the Static VAR Compensator. The study results reveal that, with the newly proposed technique, a voltage stability margin has increased even when load demands are increasing under a single contingency condition. In addition, when installing FACTS device in the proper location, generators can control power transfer on transmission lines and it can protect lines overload which result in the Multi-Lines buses security enhancement.

Keywords: FACTS device, Primary Generation Response, Multi-Lines Bus Security, Contingency, Sensitivity Analysis

1 INTRODUCTION

In a large power system has many buses in system which it connected with transmission lines for power system stability. Each of bus may connected with many transmission lines, loads, Generator, transformer or FACTS devices which in this paper has called this bus is the Multi-Lines bus. Then, the Multi lines bus security assessment and protection planning have necessary to study especially in case of the transmission line outage. The line outage impaction will make power transfer to Multi-lines bus not enough for load demands or make another transmission line on multi-lines bus over load especially under system have large solar power system integration to system [1]. This is a major problem for define method or technique to protection and reduce impaction in power system. In a study has focused on improving the voltage stability [2] and protection planning including the security assessment of Multi-lines critical voltage bus. In a study has used a newly continuation repeat power flow technique to find the critical voltage buses in power system [3]. These Multi-lines critical voltage buses data and the data from a technology assessment and financial indices study can carries to promote areas and support considering for installation the new generations. This paper presents a proper location of

FACTS device placement and a primary generation response definition for Multi-Lines buses security enhancement. The Multi-Lines bus security assessment has considered Available Transfer Capability (ATC) assessment of transmission lines connected to bus. The ATC has considered under the thermal limit in MVA which it must have more than 20%. A Power flow sensitivity analysis consists of the Generation Shift Factor (GSF) and the Line Outage Distribution Factor (LODF). The GSF data has carried to applicate for a primary generation response definition for control power transfer on these transmission lines. This study have used a Modified-Thailand's power system during peak load in 2014 [4] for a system base case. The system base case have generation capacity 27,400MW include solar power generation, Load demand 26,810MW and losses 590MW. The system base case has set a violation limit control of voltage at 0.9-1.1 p.u. and %loading of transmission line not more than 100%. The Study results have used POWER WORLD program and DIgSILENT program for simulation and analysis.

2 POWER FLOW SENSITIVITY ANALYSIS

In this paper have two sensitivity factors [5] for power transfer analysis to power system security enhancement planning.

2.1 Generation Shift Factor (GSF)

The Generation Shift Factors calculate the effect of change in generation on the line flows, as shown in equation (1).

$$a_{li} = \frac{\Delta f_i}{\Delta p_i} \quad (1)$$

It is assumed here that the change in generation at the itl bus is picked up by the reference bus. The new power flows in each line can be found in equation (2).

$$f_l^{new} = f_l^{old} + a_{li}\Delta p_i; \forall l = 1, 2, \dots, L \quad (2)$$

Where;

f_l^{old} is the power flow in the lth line before the itl generator outage,
 $A(li)$ is the linear Generation Shift Factor for the lth line for a change in output of lth generator,
 Δf_l is the MW change in power flow in the lth line,
 Δp_i is the change in generation at the itl line

2.2 Line Outage Distribution Factor (LODF)

The line Outage Distribution Factors are used to check line overloading which the result of transmission line and defined in equation (3) then the new line flows can show in equation (4),

$$d_{ik} = \frac{\Delta f_l}{f_k^{old}} \quad (3)$$

Where;

d_{ik} is the line Outage distribution factors for line l after an outage of line k ,
 Δf_l is the change in MW flow in line l due to the outage of line k ,
 f_k^{old} is the flow in line k before its outage.

$$f_l^{new} = f_l^{old} + d_{ik}f_{lk}^{old} \quad (4)$$

3 THE AVAILABLE TRANSFER CAPABILITY

In this paper purpose to study and evaluate Available Transfer Capability (ATC) by using limits for various power system elements include MVA (or Amp) limits on transmission lines which this limit is the Total Transfer Capability (TTC) of transmission line. The Limits for transmission lines are always entered in MVA from the MVA rating using the equation (5).

$$Limit_{MVA} = \frac{Limit_{AMP}\sqrt{3}|V_N|}{10^6} \quad (5)$$

Where;

$Limit_{AMP}$ is Limit in Amperes,

$Limit_{MVA}$ is Limit in MVAs,

V_N is nominal voltage in Volts

The North American Electric Reliability Council (NERC) defined ATC as measure of the transfer capability remaining of each transmission lines in the transmission line network. The TTC can be express in equation (7).

$$TTC = ATC + TRM + (ETC + CBM) \quad (7)$$

In this paper, the margins of TRM and CBM are not consider and using NERC ATC terminology and the committed Uses is real power transfer on transmission line. Then the ATC here can show in equation (8).

$$ATC = TTC - Committed\ Uses \quad (8)$$

Where;

TTC is Total Transfer Capability,
 ATC is Available Transfer Capability,
 TRM is Transfer Reliability Margin,
 ETC is Existing Transfer Capability,
 CBM is Capability Benefit Margin

3 VOLTAGE STABILITY LIMIT

3.1 Voltage Stability Concept [6]

The Voltage stability is ability of a power system to maintain the voltage at all buses under normal operating conditions and contingency condition. The voltage collapse can lead the power system to unstable which can show the locus of critical voltage point each of power factors with the V-P curve at bus voltage as show in figure 1. The V-P curve analysis process in this study will use power flow solutions for increasing power transfers of MW by increase Load demand factor and decrease generation capacity in area.

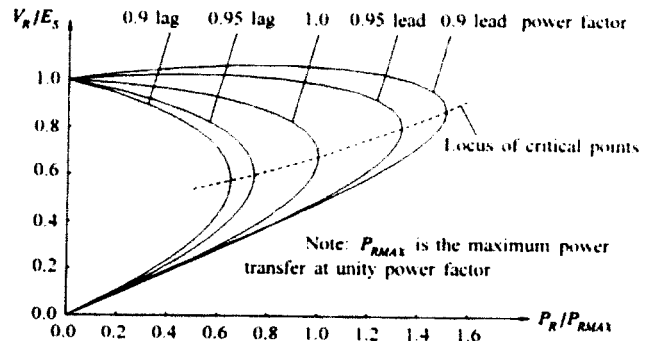


Figure 1. The VR-PR curve at bus voltage [6]

3.2 Static VAR Compensator (SVC)

The FACTS device in this study have focused on Static Var Compensator (SVC) for improve voltage stability. The type of SVC for study has used the shunt capacitor bank and switches ON-OFF with circuit breaker (CB) as show in figure 2.

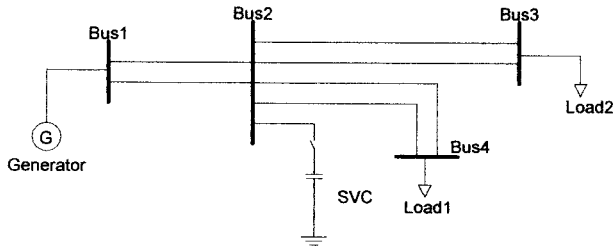


Figure 2. A simple diagram for installing and control of SVC

The figure 1 show a simple diagram for installing and control by use CB of the SVC in this study which the capacity of SVC have presented in MVAR. The capacitor values can calculate with equation (9).

$$C = \frac{Q}{2\pi f V_{rms}^2} \quad (9)$$

Where;

C is Capacitor (μF),

Q is Reactive power (MVAR),

F is Frequency (Hz),

V is Bus voltage (rms)

4 A STUDY RESULTS

A study results have focused on a proper location of FACTS device placement and a primary generation response definition for Multi-Lines buses security enhancement under contingency condition. In this study have used a modify Thailand power system in 2014 for system base which can separate the study results in two main topics.

4.1 A Proper Location of FACTS Device Placement

In this study results used repeated power flow technique for location definition of FACTS Device Placement by focused into Northeastern of Thailand power system. This technique has used Load demand increasing by considered voltage stability limit to find the critical voltage buses (CVB). The step size for load increasing factors is 0.01 per step which the repeated process will run until system unstable. The CVB in this study results is a proper location of FACTS device placement which the critical voltage buses results have shown in figure 3.

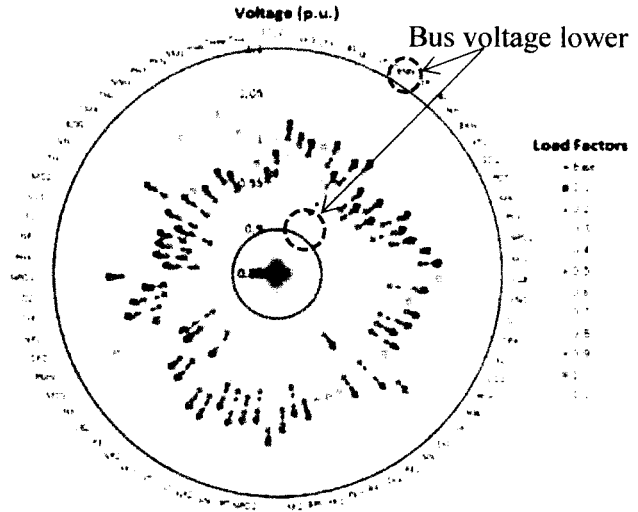


Figure 3. Voltage profile in case load demands factors in area increasing until system unstable

In figure 3 found one critical voltage bus (BNN bus) which this bus is a proper location of FACTS device placement for improves the voltage stability in area. The voltage variation of this CVB can show in figure 4.

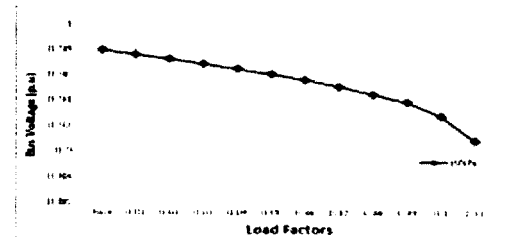


Figure 4. The CVB (BNN bus) voltage variation in case load demands factors in area increasing

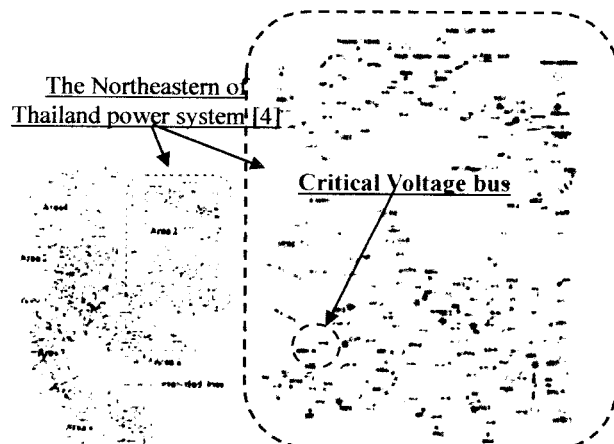


Figure 5. The Installation of SVC plant at Critical voltage bus (BNN) for testing and prove voltage recovery

The figure 5 has shown the location of critical voltage bus in system can show in figure 6 and the testing results for voltage recovery with install the SVC can show in figure 7.

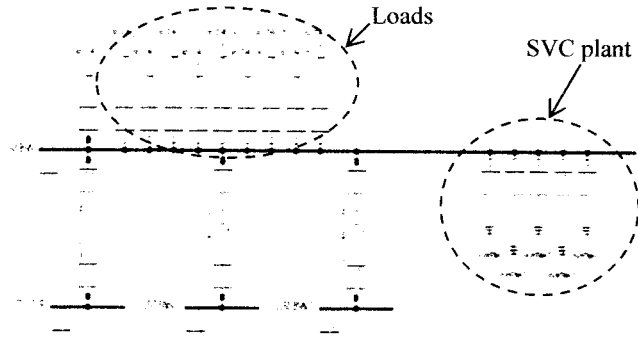


Figure 6. The Installation of SVC plant at Critical voltage bus (BNN) for testing and prove voltage recovery

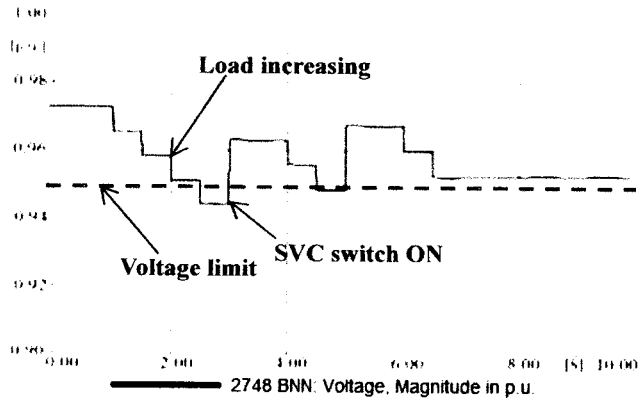


Figure 7. Voltage variation during load increasing and SVC switch ON

The Figure 6 has shown the critical voltage bus (BNN) which installed SVC and Loads for voltage recovery testing with SVC. The testing has switched on load to bus with 4 MW/step until bus voltage lower 0.95 p.u. and after that the SVC will switch ON until voltage recovery higher 0.95 p.u. with 10MVAR/step. The study results as shown in figure 7.

4.2 A Primary Generation Response Definition for Multi-Line Bus Security Enhancement

In this study have focusing on security assessment and primary generation respond definition for multi-line bus security enhancement. The multi-line bus for study has focus on inter-tied line buses which these buses have important for power transfer during areas. The multi-line bus for study has connected transmission line from area5 and Area1 as show in figure 8 which this bus (KK3_2803) has 12 transmission lines and one SVC.

A) A Study Multi-Line Bus Security assessment results the Multi-Line Bus Security assessment have use the Available Transfer Capability (ATC) include the LODF analysis under contingency condition. The contingency condition in this study has focus on transmission line outage or trip. The study results have shown in table 1 and 2. In a table 1 found in power system normal condition the transmission lines connected to multi-line bus have the ATC not less than 20% that mean this bus has high security by all transmission line have margin for support load demand increasing. But, under contingency condition each of transmission line outage that found transmission line no. 2803-2806 when it outage it make another line over load and make The ATC of transmission line less than 20% as shown in figure 8.

Table 1. The ATC assessment of transmission lines on KK3_2803 bus

Available Transfer Capability (ATC) of Transmission lines													
Bus No.	Base	2803											
2802-1	61.44	Trip	38.6	61.1	61.1	61.3	61.3	61.4	61.4	61.3	61.3	56.2	56.2
2802-2	61.44	38.6	Trip	61.1	61.1	61.3	61.3	61.4	61.4	61.3	61.3	56.2	56.2
2804-1	81.64	81.2	81.2	Trip	66.4	81.8	81.8	82.1	82.1	81.8	81.8	81.3	81.3
2804-2	81.64	81.2	81.2	66.4	Trip	81.8	81.8	82.1	82.1	81.8	81.8	81.3	81.3
2805-1	72.55	72.9	72.9	72.7	72.7	Trip	65.0	72.3	72.3	65.9	65.9	72.6	72.6
2805-2	72.55	72.9	72.9	72.7	72.7	65.0	Trip	72.3	72.3	65.9	65.9	72.6	72.6
2806-1	57.09	59.3	59.3	59.3	59.3	55.5	55.5	Trip	17.6	55.7	55.7	57.7	57.7
2806-2	57.09	59.3	59.3	59.3	59.3	55.5	55.5	17.6	Trip	55.7	55.7	57.7	57.7
2813-1	72.6	72.9	72.9	72.7	72.7	65.0	65.0	72.4	72.4	Trip	62.6	72.7	72.7
2813-2	72.6	72.9	72.9	72.7	72.7	65.0	65.0	72.4	72.4	62.6	Trip	72.7	72.7
4807-1	74.7	70.2	70.2	74.6	74.6	74.6	74.6	74.8	74.8	64.6	64.6	Trip	61.4
4807-2	74.7	70.2	70.2	74.6	74.6	74.6	74.6	74.8	74.8	64.6	64.6	61.4	Trip

Table 2. The LODF analysis of transmission lines on KK3_2803bus

Line Outage Distribution Factors (LODF)												
Bus Number	2803											
	Trip											
2802-1	55.9	-0.5	-0.5	-1.2	-1.2	-0.6	-0.6	-1.1	-1.1	-18.3	-18.3	
2802-2	55.9	-0.5	-0.5	-1.2	-1.2	-0.6	-0.6	-1.1	-1.1	-18.3	-18.3	
2804-1	2.0	84.3	2.4	2.4	2.0	2.0	2.1	2.1	1.0	1.0		
2804-2	2.0	84.3	2.4	2.4	2.0	2.0	2.1	2.1	1.0	1.0		
2805-1	1.3	0.6	0.6	26.5	0.5	0.5	23.6	23.6	0.7	0.7		
2805-2	1.3	0.6	0.6	26.5	0.5	0.5	23.6	23.6	0.7	0.7		
2806-1	7.0	5.9	5.9	5.8	5.8	92.2	5.1	5.1	3.5	3.5		
2806-2	7.0	5.9	5.9	5.8	5.8	92.2	5.1	5.1	3.5	3.5		
2813-1	1.3	0.6	0.6	26.8	0.5	0.5	35.6	0.7	0.7			
2813-2	1.3	0.6	0.6	26.8	0.5	0.5	35.6	0.7	0.7			
4807-1	10.4	0.1	0.1	0.4	0.4	0.2	0.3	0.3	51.6	51.6		
4807-2	10.4	0.1	0.1	0.4	0.4	0.2	0.3	0.3	51.6	51.6		

Table 3. The GSF analysis of transmission lines on KK3_2803bus

Generation Shift Factor (GSF)											
2803-2802		2803-2804		2803-2805		2803-2806		2803-2813		2803-4807	
Gen. No.	GSF	Gen. No.	GSF	Gen. No.	GSF	Gen. No.	GSF	Gen. No.	GSF	Gen. No.	GSF
2011	0.477	2021	0.846	2052	0.325	2021	-0.117	2021	-0.013	2021	0.542
2012	0.477	2022	0.846	2054	0.325	2022	-0.117	2022	-0.013	2022	0.542
5041	0.464	2024	0.846	2053	0.325	2024	-0.117	2024	-0.013	2024	0.542
5042	0.464	2025	0.846	2063	0.325	2025	-0.117	2025	-0.013	2025	0.542
5045	0.464	2023	0.846	2051	0.325	2023	-0.117	2023	-0.013	2023	0.542
5043	0.464	2026	0.846	2064	0.325	2026	-0.117	2026	-0.013	2026	0.542
5046	0.464	2734	0.444	2004	0.324	4011	-0.132	4034	-0.025	2041	0.534
5044	0.464	2735	0.444	2040	0.324	4033	-0.132	4035	-0.025	2044	0.534

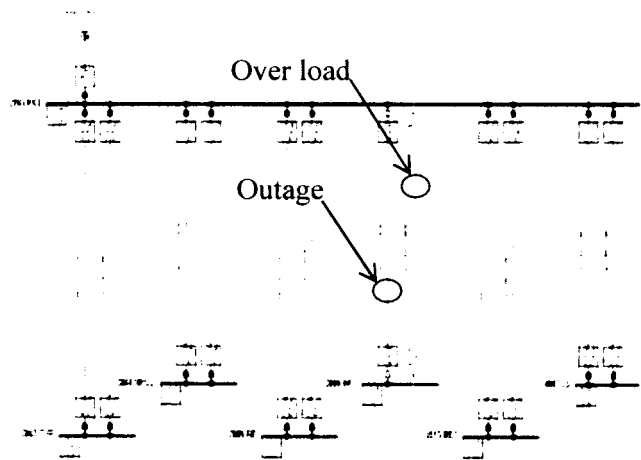


Figure 8. The KK3_2803 bus in case transmission line no. 2803-2806_1 outage

and in a table 2 that show the LODF analysis of transmission lines on KK3_2803bus which it make to know important transmission lines for support power transfer under each of transmission line outage.

B) A Primary Generation Response Definition the primary generation responds definition have used GSF data for select generation by select the generator has maximum of GSF which the GSF data of power transfer each of transmission line have shown in table 3. In case of transmission line no. 2803-2806_1 outage and it make line no. 2803-2806_2 over load. Then the primary generation response group is generator no. 2021, 2022, 2024, 2025, 2023 and 2026 but in this case will have select generator no. 2021, 2022, 2024 and 2025 when compare generator capacity that found it have same and high capacity. The study results have shown in figure 9-11. In the figure 9 shown the ATC recovery of transmission line with definition of primary response generation which found it can recovery of the ATC of line no. 2803-2806_2 increase and it not over load.