

State estimation with and without FACTS controller SVC using WLS Algorithm

Nikita Abraham¹ Dr. R. Jegatheesan²

^{1,2} Department of Electrical and Electronics Engineering

^{1,2} S R M University, Tamil Nadu, Chennai

Abstract---Flexible AC Transmission System (FACTS) technology, which aims at increasing system operation flexibility, appears as an attractive alternative. FACTS controllers are included in an electrical power system to overcome operational problems. Static VAR compensator (SVC) is a shunt connected static VAR generator (or absorber) whose output is designed to draw capacitive or inductive current so as to maintain normal voltage at the bus with which the SVC is connected. SVC can be incorporated to an electrical power system using WLS state estimation algorithm. In this paper various changes made in Jacobean matrix when SVC is added. Comparison with and without SVC done with IEEE 3bus and IEEE 14bus at different locations then voltage magnitude and phase angle variations at each node determined.

Keywords: FACTS controllers, Static VAR compensator (SVC), Jacobian matrix, WLS algorithm

I. INTRODUCTION

Transmission systems are undergoing continuous changes mainly from the strong increase in interconnected power transfers, opening of the market for delivery of cheaper energy to the customers, and economic and ecological constraints which delay the building of new transmission facilities. Construction of new transmission lines are difficult due to growing power plant capacity and energy demand so to make the existing transmission lines more efficient methods are adopted. The need for more efficient power systems management, and the fast development of power electronics based on new and powerful semiconductor devices, have given rise to innovative technologies, such as FACTS controllers[1]. FACTS CONTROLLERS are power electronic based system and other static equipment that provide control of one or more AC transmission parameter. The concept of flexible AC transmission systems (FACTS) was proposed by Hingorani in the 1860s, many various FACTS devices have been utilized to meet a growing demand of the transfer capabilities due to developing wheeling transactions in the deregulation environment. Nowadays, FACTS devices are also used in high-voltage distribution systems for different purposes. The main advantage of FACTS controllers is to control the line parameters such as voltage, voltage angle and line reactance. There are three main categories of FACTS devices, i.e. series-connected devices, shunt-connected devices and combined series-shunt connected. SVC and STATCOM(Static Synchronous Compensator) are used as shunt controllers. TCSC(Thyristor controlled series capacitor) and SSSC(Static synchronous series compensator) are used as series controllers. UPFC (Unified

power flow controller) and IPFC (Inter line power flow controller) used as combined series and shunt controller.

According to the IEEE definition, a Static VAR Compensator (SVC) is a shunt connected static VAR generator or absorber whose output is adjusted to exchange capacitive or inductive current to maintain or control specific parameters of the electrical power system (typically, the bus voltage) [6]. It is mainly used for voltage regulation. For voltage control SVC is usually installed at the receiving node of the transmission lines.

Enlargement of interconnected electric power system and the increasingly complexity of electric power system structure, gives rise to energy management system (EMS) in critical for modern power system. State estimation plays an important role in EMS, which provides a reliable and consistent system data by processing real time redundant telemetered and pseudo measurements. These measurements typically consist of bus voltage magnitudes, real and reactive line flows and power injection. Processing these real time data, different kinds of advanced application software in EMS are derived, such as voltage stability analyses, security constraint and transient stability analysis.

Approach to incorporating FACTS controllers in WLS state estimation Algorithm made by decoupling the gain matrix into three sets of equations, which are solved sequentially for the state variables of the AC system, DC system and FACTS devices, respectively. Various changes are made with Jacobean matrix also. The SVC with variable reactance can be adjusted automatically as a function of the firing angle which is taken as state variable. It should be noted that near the resonant point, small variations of the firing angle will induce large changes in the reactance, which in turn may lead to ill-conditioned controller's power flow equations and Jacobean terms [1]. Comparison with and without FACTS controllers using WLS state estimation Algorithm has been done. Further a Matlab code is developed for the proposed approach and applied to IEEE 3, 14 bus system and the results are tabulated.

II. SVC

A. Modeling of SVC

SVC device is a parallel combination of thyristor controlled reactor with a bank of capacitors. It's a shunt connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude where it is connected to the AC network. Mainly used for voltage regulation. As an important component for voltage control, it is usually installed at the receiving node of the transmission lines. Fig.1 shows a SVC model with step down transformer.

2. Set iteration count $k = 0$; Initialize the state vector x^k , typically as a flat start.
3. Knowing the measurement equations, Compute the measurement Jacobian matrix $H(x^k)$.
4. Calculate the gain matrix, $G(x^k)$ using

$$G(x^k) = H^T(x^k)R^{-1}H(x^k)$$
5. Calculate the right hand side vector t^k , given by

$$t^k = H^T(x^k)R^{-1}[z - h(x^k)]$$
6. Decompose $G(x^k)$ and solve for

$$G(x^k)\Delta x^k = H^T(x^k)R^{-1}[z - h(x^k)]$$
 for Δx^k ,
 Update $x^{k+1} = x^k + \Delta x^k$.
7. Test for convergence, $\max. |\Delta x^k| \leq \epsilon$?
8. If no, set $k = k + 1$; go to step 3. Else, stop.

B. WLS Algorithm with facts controllers

Changes are made with WLS algorithm.

1. Read the system input data; line data, bus data, generator and load data.
2. Modified admittance matrix Y bus when svc added to node k.
3. Combining the SVC power equations with network equation,
4. The conventional jacobian matrix are formed due to the inclusion of SVC. The inclusion of these variables increases the dimensions of the jacobian matrix.
5. Increase in size of gain matrix.
6. Then steps are followed WLS state estimation algorithm.

C. Jacobian matrix formation with FACTS controller

Fig.4 shows the structure of the modified Jacobian where X_{nAC} stands for the AC network state variables, namely, nodal voltage magnitudes and phase angles, and R_{nF} stands for the power system controller state variables [6].

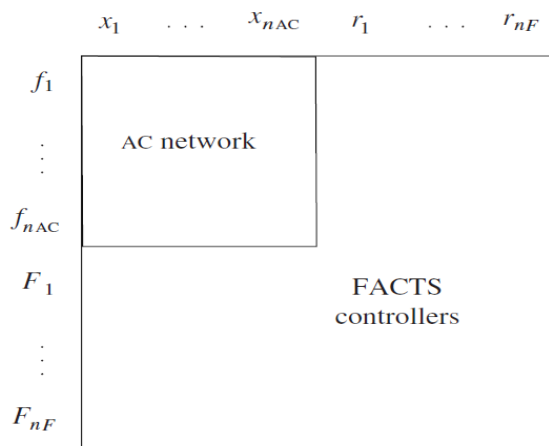


Fig.4. Augmented Jacobian

SVC added to a 3 bus system,

CASE1:

- (i) 3bus without SVC
 No. of state variables =5
 No. of measurements $z=8$
 $h=8 \times 1, h=8 \times 5, g=5 \times 5$.

- (ii) 3bus with SVC
 No. of state variables =6
 No. of measurements $z=8$
 $h=8 \times 1, h=8 \times 6, g=6 \times 6$.

CASE2:

- (i) 14bus without SVC
 No. of state variables =27
 No. of measurements $z=42$
 $h=42 \times 1, h=42 \times 27, g=27 \times 27$.

- (ii) 14bus with SVC
 No. of state variables =28
 No. of measurements $z=42$
 $h=42 \times 1, h=42 \times 28, g=28 \times 28$.

$$\hat{x} = [\theta_2 \quad \theta_3 \quad V_1 \quad V_2 \quad V_3 \quad \alpha_{svc}]$$

$$z = [p_{12} \quad p_{13} \quad P_2 \quad q_{12} \quad q_{13} \quad Q_2 \quad V_1 \quad V_2]$$

\hat{x} is the state variable vector, z is vector of measurements.

$$H_{old} = \begin{bmatrix} \hat{x}/z & \theta & V \\ \text{real power flow} & H_{11} & H_{12} \\ \text{real power injection} & H_{21} & H_{22} \\ \text{reactive power flow} & H_{31} & H_{32} \\ \text{rective power injection} & H_{41} & H_{42} \\ \text{voltage magnitue} & H_{51} & H_{52} \end{bmatrix} \quad (9)$$

Changes made when SVC is added, increase in state variable and changes in gain and corresponding residual matrix.

$$H_{new} = \begin{bmatrix} \hat{x}/z & \theta & V & \alpha_{svc} \\ \text{real power flow} & H_{11} & H_{12} & H_{13} \\ \text{real power injection} & H_{21} & H_{22} & H_{23} \\ \text{reactive power flow} & H_{31} & H_{32} & H_{33} \\ \text{rective power injection} & H_{41} & H_{42} & H_{43} \\ \text{voltage magnitue} & H_{51} & H_{52} & H_{53} \end{bmatrix} \quad (10)$$

$$H_{21new} = H_{21old} + H_{21svc}$$

$$H_{22new} = H_{22old} + H_{22svc}$$

$$H_{41new} = H_{41old} + H_{41svc}$$

$$H_{42new} = H_{42old} + H_{42svc}$$

(11)

D. First derivative of real and reactive power injections of SVC

Since $R_T = 0, P_k^{T-SVC} = 0$. So reactive power first derivative with respect to state variables are:

$$Q_{SVC} = -\frac{V_k^2}{X_L X_C} [X_L - \frac{X_C}{\pi} [2(\pi - \alpha_{SVC}) + \sin(2\alpha_{SVC})]]$$

(12)

$$\frac{\partial Q_{SVC}}{\partial V_k} = -\frac{2V_k}{X_L X_C} [X_L - \frac{X_C}{\pi} [2(\pi - \alpha_{SVC}) + \sin(2\alpha_{SVC})]]$$

(13)

$$\frac{\partial Q_{SVC}}{\partial \alpha_{SVC}} = \frac{2V_k^2}{\pi X_L} [\cos(2\alpha_{SVC}) - 1]$$

(14)

IV. RESULT

In case of a 3bus system SVC is installed at node 2. The SVC connected at node 2 is assumed without step-down transformer and reactance's of $X_c = 1.07$ pu, $X_L = 0.288$ pu and a transformer impedance of $Z_T = j0.3$ pu . The firing angle can be varied from $90^\circ \leq \alpha_{SVC} \leq 180^\circ$. In this case firing angle's initial condition is $\alpha_{SVC} = 130^\circ$ [1]. The voltage specified calculated as 0.9845. For 14bus also SVC is added at different nodes, i.e. node 7, node 10, node 12 and node 14. The voltage specified calculated as 1.0405. Variations in voltage magnitude and voltage phase angle have been obtained with and without SVC.

A. Result of 3 bus

Bus no.	Without SVC		With SVC	
	VOLTAGE MAGNITUDE	PHASE ANGLE	VOLTAGE MAGNITUDE	PHASE ANGLE
1	0.9996	0.0000	1.0118	0.0000
2	0.9742	-1.2475	0.9850	-1.4463
3	0.9439	-2.7457	0.9114	-3.6552

Table. 2: estimated voltage magnitudes and voltage phase angles for IEEE3 bus SVC added at node 2 with specific voltage 0.9850.

Bus no.	Without SVC		With SVC	
	VOLTAGE MAGNITUDE	PHASE ANGLE	VOLTAGE MAGNITUDE	PHASE ANGLE
1	1.0606	0.0000	1.0600	0.0000
2	1.0453	-4.8628	1.0442	-4.9795
3	1.0102	-12.4056	1.0090	-12.7542
4	1.0145	-9.9841	1.0115	-10.2283
5	1.0179	-8.5454	1.0153	-8.7483
6	1.0706	-14.0875	1.0752	-14.8188
7	1.0467	-12.8970	1.0443	-13.3039
8	1.0806	-12.8970	1.0787	-13.3041
9	1.0316	-14.4393	1.0293	-14.9291

10	1.0310	-14.6530	1.0405	-15.4142
11	1.0470	-14.4864	1.0539	-15.2308
12	1.0540	-14.9194	1.0586	-15.6609
13	1.0474	-14.9523	1.0520	-15.6946
14	1.0204	-15.6641	1.0209	-16.2887

Table. 3: estimated voltage magnitudes and voltage phase angles for IEEE14 bus SVC added at node 10 with specific voltage 1.0405.

V. CONCLUSION

In this paper SVC with a controlled shunt susceptance (B_{T-SVC}) which inject reactive power (α_{SVC}) into thereby increasing the bus voltage back to its net desired voltage level have been obtained. Particular voltage attained at each nodes where SVC have been added. Coding carried out with IEEE 3-bus, 14-bus to illustrate the performance of the developed state estimator and variation of voltage magnitude and phase angle at each bus. It is demonstrated that the algorithm retains good convergence property as the traditional WLS method. Size of Jacobian increased and various changes are made in WLS algorithm.

REFERENCES

- [1] Zamora-Cárdenas and Claudio R. Fuerte-Esquivel "State estimation of power systems containing facts controllers" in elsevier , january 2011.
- [2] Nery Taranto,et,al, "Representation of FACTS devices in power system economic dispatch," *IEEE Transactions on Power Systems*, vol. 7, n 2, pp. 572-576 ,May, 1992.
- [3] Lu, C.N., "Modelling multiple injection bus in power system state estimation, " *IEE Proceedings, Part C: Generation, Transmission and Distribution*, vol. 140, n 6, pp 455-461 ,November 1993.
- [4] Ding Qifeng,et.al, "State estimation for power system embedded with FACTS devices and MTDC systems by a sequential solution approach" *Electric Power Systems Research*, vol.55, pp.147-156, 2000.
- [5] Ali Abur and Antonio Gomez Exposito "Power System State Estimation Theory and Implementation" Marce Dekker Ltd ,2004.
- [6] Enrique Acha , Claudio R. Fuerte-Esquivel.Hugo Ambriz-Pérez ,Ce'sar Angeles-Camacho, "Modelling and Simulation in power networks" John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester,West Sussex PO19 8SQ, England ,2004.
- [7] N.M.NorandR.Jegatheesan "State Estimation using constructed Jacobian(SECJ)EmbeddedwithUPFC".
- [8] <http://www.ee.washington.edu/research/pstca/>.