Journal of Electrical Engineering Science., 1 (1), 2010
ISSN: 2008-9864

Using ANFIS as Indicator in the Networks Containing SVC and STATCOM for Voltage Collapse Phenomena

Nemat Talebi[1];Mansoor Sheykhan[2]

[1,2] Islamic Azad Univarsity South Tehran Branch, Nemat-Talebi@azad.ac.ir, Msheykhan@azad.ac.ir

Abstract : This paper focuses on using an ANFIS indicator for it's proximity to collapse point with emphsizing on application of two Flexible AC Transmission System (FACTS) devices' namely, Static Var Compensator (SVC) and Static Compensator (STATCOM), In order to study the effects on voltage collapse phenomena in power systems. Based on system results at the point of collapse 'Application of these devices loadability or increase could increase loadability margin to collapse point. Also,ANFIS as an indicator for proximity to collapse point has been applied succesfuly. The IEEE 14 bus test system is used to illustrate the effects of FACTS devices on voltage collapse phenomena and applying of ANFIS as an indicator for proximity index simulations.

***Keywords**: ANFIS, SVC, STATCOM, Voltage Collapse, Loadability Margin.*

استفاده از ANFIS به عنوان نشانگری برای پدیده فرو افتادن ولتاژ در شبکه‌های دارای ادوات FACTS

نعمت طالبی[۱]؛ منصور شیخان[۲]

چکیده: این مقاله برروی استفاده از نشانگر ANFIS برای تعیین نزدیکی به نقطه فروافتادن ولتاژ در سیستم‌های قدرتی که ادوات FACTS به خصوص SCATOM, SVC وجود دارند متمرکز است تا اثرات این وسایل را برروی پدیده فروافتادن در سیستم‌های قدرت مورد مطالعه قرار دهد. همچنین استفاده از ANFIS به عنوان نشانگری برای تعیین نزدیکی به نقطه مرز افتادن بطور موفقیت آمیزی استفاده شده است. سیستم آزمون ۱۴ شینه IEEE برای نمایش اثر ادوات FACTS بر روی پدیده فروافتادن ولتاژ و بکارگیری ANFIS به عنوان نشانگری برای نزدیکی به نقطه فروافتادن مورد شبیه سازی قرار گرفته است.

کلمات کلیدی: حاشیه بارگذاری سیستم، فاصله تا نقطه فرو افتادن ولتاژ، فرو افتادن ولتاژ، ANFIS، SVC، STATCOM.

1. Introduction

Voltage collapse problems in power systems have been a permanent concern for the electric utilities, as several major black outs through out the world have been directly associated to this phenomena, e.g. WSCC July 1996 and etc. Many analysis methods have been proposed and currently used for the study of this problem [1,2,3]. Most of these thechniques are based on the identification of system equilibria where the corresponding jacobians become singular. These equilibrium points are typically refferd to point of voltage collapse and can be mathematically associated to saddle-node bifurcation [4,5].

The voltage collapse point are also known as maximum loadability point. In fact, the voltage collapse problem can be restated as an optimization problem where the objective function is to maximize certain system parameters typically associated to load levels [6,7,8,9]. Hence, voltage collapse techniques may also be used to compute the maximum power that can be transmitted through the transmission system. In the new competitive energy market litretuers also known as total transfer capability or as available transfer capability(ATC) [10].

It is well known that shunt and series compensation can be used to increase the maximum transfer capabilites of power networks [11]. With the improvments in current and voltage handling capabilities of power electronic devices that have allowed for development of flexible ac transmission system devices. The possibility has arisen to using different types of controllers for efficient shunt and series compensation. Thus, FACTS devices based on shunt connection on the network such as static var compensators (SVC) and static compensator (STATCOM) are being used by several electric utilities to compensate their systems [12]. Recently, various types of devices for shunt and series compensation based on voltage source convertors (VSC) 'namely, SSSC , UPFC , have been proposed and implemented [13]. This paper concentrate on studying the efffects of SVC and STATCOM on voltage collapse phenomena using continuation power flow (CPF) method [14,15].

Adaptive Neuro Fuzzy Inference System (ANFIS) as an intelligent system uses of two major feature of Neural networks learning capability and also, fuzzy logic inference capabilty. So, ANFIS is very suitable for chalenging situations where complex mathematical expression and involving uncertinity with inferences. In large scale power sytem calculating loadabilty margin is complicated problem. So, learning of conceptual mathematical model based on lerrning phenomena at neural networks adequately suiteable in proximity prediction to voltage collapse point and also, fuzzy inference feature suitable for uncertinity contained in operating point.

Section 2 briefly introduces the basic mathematical tools required for the analysis of voltage collapse phenomena. In section 3 a detailed describtion of SVC and STATCOM models are given. Section 3b introduce the ANFIS structure. Section 4 is depicted to simulation of voltage collapse phenomena on IEEE 14 bus test system with implementing SVC and STATCOM and applying ANFIS. Finally, section 5 summrizes the main points of this paper and discusses future reaserch directions.

2. Voltage collapse

Voltage collapse studies and their related tools are typically based on the following general mathemathical descriptions of the system :

$$\begin{aligned} \overset{\circ}{x} &= f(x, y, \lambda, p) \\ 0 &= g(x, y, \lambda, p) \end{aligned} \qquad (1)$$

Where $x \in \Re^n$ represents the system state variables, corrosponding to dynamical states of generators, loads, and any other time varying element in the system such as FACTS devices; $y \in \Re^n$ corrosponds to the algebraic variables, usually associated to the transmission system and steady state element models, such as some generators and loads in the network ; $\lambda \in \Re^l$ stands for a set of uncontrolled parameters that drive the system to voltage collapse, which are typically used to represent system demand. Vector $p \in \Re^k$ is used here to represent system parameters that are directly controllable, such as shunt and series compensation levels.

Based on equation (1) the voltaage collapse point may be defined, under certain assumptions, as the equblirium point whre the related system jacobian is singular, i.e. the point $(x_0, y_0, \lambda_0, p_0)$ where

$$\begin{bmatrix} f(x, y, \lambda, p) \\ g(x, y, \lambda, p) \end{bmatrix} = F(z, \lambda, p) = 0 \qquad (2)$$

and $D_xF|_0$ has a zero eigenvalue[15]. This equblirium is typically associated to a saddle-node bifurcation point.

For a given set of controllable parameters P_0, voltage collapse studies usually concentrate on determining the collapse or bifurcation point (x_0, y_0, λ_0), where λ_0 typically corrosponds to the maximum loading level or loadability margin in P.U. , %, MW or MVA depending on how the load variation are defined. Based on bifurcation theory , two basic tools have been defined and applied to computation of this collapse point,namely, direct and continuation methods [16].

In voltage collapse studies, the continuation method shows many advantages, so, most of the reaserchers apply this technique to trace voltage profile at various buses of the test power system, with respect to changes of loading level λ, namely, Continuation Power Flow (CPF).

In this paper the continuation power flow algorithem with smooth changes of loading level at various buses of the system, is chossen for simulation purpose.

3. SVC and STATCOM models and Introducing ANFIS

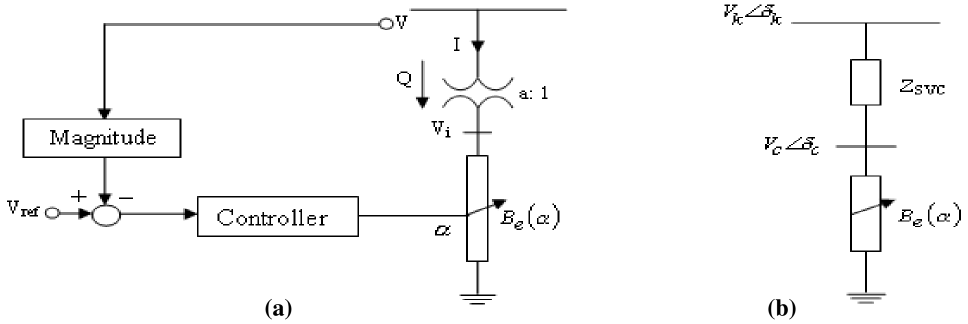
A-1) SVC

Basic model for SVC built around Thyristor controlled reactor (TCR).Therfore ' the FC-TCR structure depicted in fig. 1, is used in this paper. The TCR consist of a fixed reactor of inductance L and a bi-directional thyristor valve. The thyristor valves are fired symmetrically in an angle α control range from 90^0 to 180^0,with respect to the capacitor voltage. The valves automatically turn off approximately at current zero crossing.

The steady state V-I charactristics for this type controller are depicted in fig. 2 , and corrosponds to the well-known control charactristics of a tyoical SVC. A SVC steady state model can be shown with the equations representing these steady state charactristics; thus, the power flow equations of the SVC in this case are

$$\begin{bmatrix} V_k - V_{\mathrm{Re}f} - X_{SL}.I \\ g_1(\alpha, V, V_k, I, Q, Be) \end{bmatrix} = 0 \qquad (3)$$

$$g_1(\alpha, V, V_k, I, Q, B_e) = \begin{bmatrix} Be - \dfrac{2\alpha - Sin2\alpha - \pi(2 - X_l / X_c)}{\pi X_L} \\ I + V_i Be \\ Q + V_i^2 Be \end{bmatrix} = 0 \qquad (4)$$



(a) (b)

Fig. 1. (a) basic construction of SVC (b) simplified electric model

which can be directly included in any power flow program.

For the steady state model to be complete, all SVC controll limits should be adequately represented.

A-2) STATCOM

The STATCOM is assumed to be connected at buse K as illustrated in fig. 3. The STATCOM model is not loss less, i.e. , the active power P at node K absorbed by internal componenets of STATCOM. Thus, the STATCOM can be represented by the following set of equations, which include control system equations and assuming sinusoidal current in the STATCOM [18,19]. where most variables are defined on figure 3.

$$\begin{bmatrix} V_k - V_{\mathrm{Re}\,f} - Z_{sh}.I \\ g_1(V_{sh}, V_k, I_{sh}, Q, P) \end{bmatrix} = 0 \qquad (5)$$

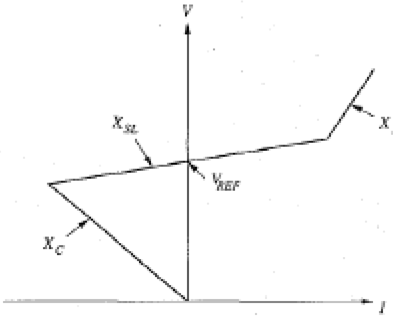


Fig. 2. SVC steady state charactristic

$$g_1(V_{sh}, V_k, I_{sh}, Q, P) = \begin{bmatrix} P_k - G_{sh} V_k^{\,2} + V_k V_{sh} Y_{sh}\, Cos(\delta_k - \delta_{sh} - \theta_{sh}) \\ Q_k - V_k^2 B_{sh} + V_k V_{sh} Y_{sh}\; Sin(\delta_k - \delta_{sh} - \theta_{sh}) \\ \sqrt{P_k^2 + Q_k^2} = I_{sh}.V_k \end{bmatrix} = 0 \qquad (6)$$

A steady state model for this STATCOM controller can be presented with equations on (5) wich Containing steady state control Charactristics. STATCOM can only preform reactive power and does not inject real power to system. But due to lossey components of the STATCOM it absorbes real power from the connected bus K [18,19].

B) Introducing ANFIS

Adaptive Neuro Fuzzy Inference System (ANFIS) is a network that’s be able to adapet itself with learning process. ANFIS performance is like to Fuzzy inference systems and it works based on rules that have been learned at learning process. If we assume a fuzzy system with two inputs x,y and one output z , it can be represented with the fuzzy rules as below.

$$\begin{aligned} &Rule\ 1: \\ &if\ x\ is\ A_1\ and\ \ y\ is\ B_1\ then\ \ f_1 = p_1 x + q_1 y + r_1 \\ &Rule\ 2: \\ &if\ x\ is\ A_2\ and\ \ y\ is\ B_2\ then\ \ f_2 = p_2 x + q_2 y + r_2 \end{aligned} \qquad (7)$$

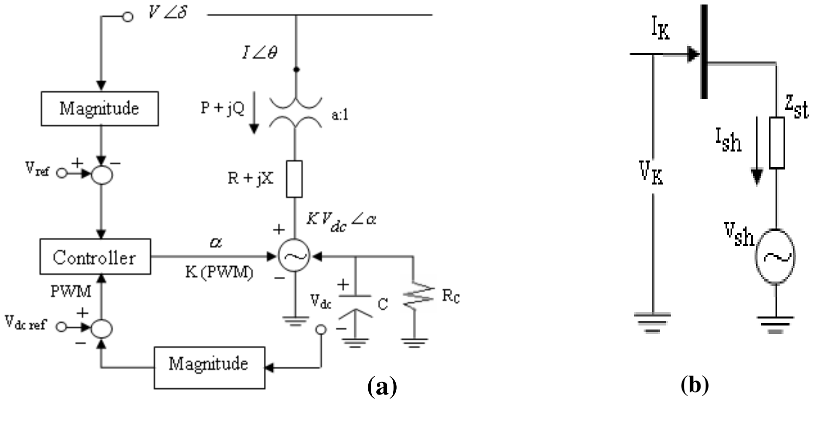


Fig. 3. (a)STATCOM bus voltage control (b) simplifed electric model

Also, if useing centres averaging defuzzification method the outputs can be defined [20].

$$f = \frac{w_1 f_1 + w_2 f_2}{w_1 + w_2} = \overline{w}_1 f_1 + \overline{w}_2 f_2 \quad st \quad \overline{w}_1 = \frac{w_1}{w_1 + w_2}, \quad \overline{w}_2 = \frac{w_2}{w_1 + w_2} \qquad (8)$$

The ANFIS network structure that's equivalent to the above sytsem (Eq. 7 &Eq. 8) shown at the Fig. 4.

Briefly intoducing the ANFIS structure layers so, layer one transforms the crisp inputs to fuzzy quantities by passing through membership functions that often choosed bell type functions. Layer two implements a product operation on the outputs of previous layer. Layer three normalize the ouputs of the layer two. The fourth layer applies product operation on the previous layer output and inputs to the network. Finally, layer five adds the outputs the fourth layer and preforms the ANFIS network outputs that is simillar to Sugeno type fuzzy systems [21].

Learning process for the ANFIS networks can be done as same as neural networks based on Gradiant Descent , Levenberg-Marquard and Hybrid methods. Performance criteria for learning process is Least Mean Squre Error and in the simulations of this paper online backpropagation error have been used [22].

4. Simulation

An IEEE 14 bus test system was used to try models and ANFIS network discussed in this paper. The generators are modeld as standard PV buses with both P and Q limits; loads are represented as constant PQ loads. The P and Q load powers are not voltage dependent and are assumed to change as follows :

$$P_L = P_{L0}(1+\lambda) \qquad (9)$$
$$Q_L = Q_{L0}(1+\lambda)$$

Where P_{L0} and Q_{L0} represents the base case loading condition.

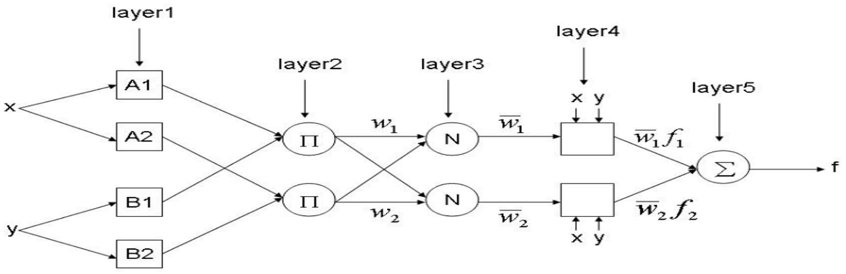


Fig. 4. ANFIS network structure

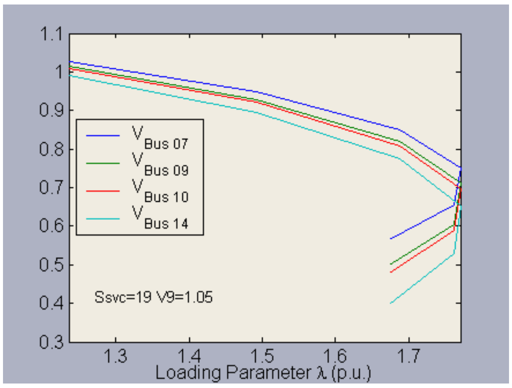


Fig. 5. base case continuation power flow

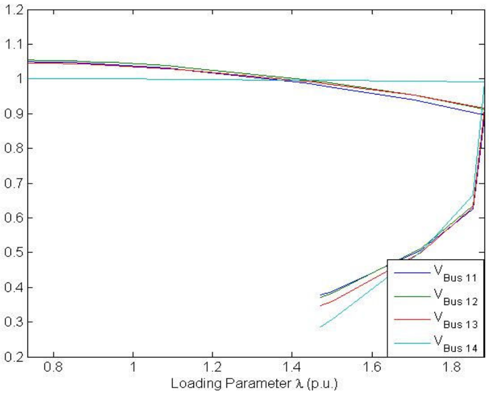


Fig. 6. SVC placement at bus 14

Fig. 5 depicts the voltage profiles of four buses identified as " critical " namely, bus No. 14 . The system presents a collapse or maximum loading point,where the system Jcobian matrix become singular at λ_0=1.7063 p.u. Based on largest entries in the right and left eigenvectors associated to the zero eigenvalue at the collapse point, bus 14 is indicated as the " critical voltage bus" needing Q support.

A) SVC

Based on collapse analysis bus 14 is targeted as the first location for an SVC. The results of locating the SVC at the desired bus are depicted in the voltage profile of fig. 6. The new maximum loading level in this condition is $\lambda_o = 1.882$ p.u.

B) STATCOM

The second type FACTS controller i.e. STATCOM is implemented on test system. A similar approach to the one followed to analyze the SVC effect on maximum loadability is used to study the corrosponding effects of a STATCOM. Fig. 7 illustrates the effects of the STATCOM on maximum loading level, when located at critical bus.

C) ANFIS Implementation

For being able to face with operation problems on large scale power systems, on line indicators to situation awreness is necessery. The ANFIS capability of learning observed data involving uncertinity and then making inference for unobserved data make it suitable for application such as this. Because at the critical situations time consuming methods as contiuation power flow could not perform realy. But having a before learned ANFIS network and with feeding the present situation available data of the power system, it can perform the loading paprameter as soon as posible (on line). So, operational aspect of an on line indicator or situation awareness tool for power system loading is critical.

The ANFIS structure used here for the above porpose is shown at the Fig. 8. For each input three Gaussian membership function is adopted. The inputs to the ANFIS network are bus voltages of the IEEE 14 bus test sytem that obatined from continuation power flow explained at previous section.

Learning process have been done succesfully and Fig. 9 shows the result. Only with three rules the resultant ANFIS network be able to work perfectly. So , it has a very simple rule base and then, responses on line.

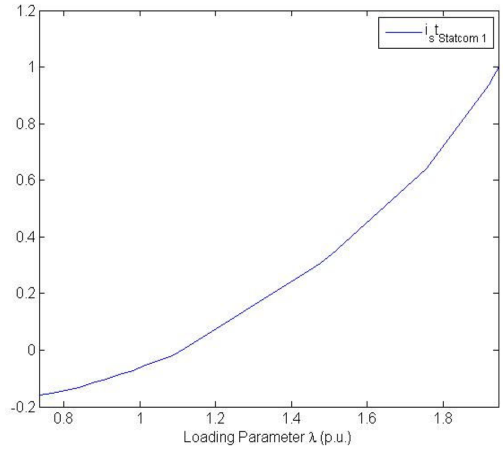


Fig. 7. ISTATCOM placement at bus 14

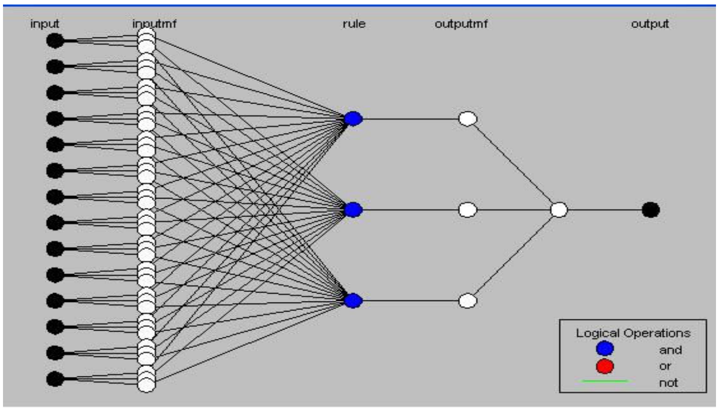
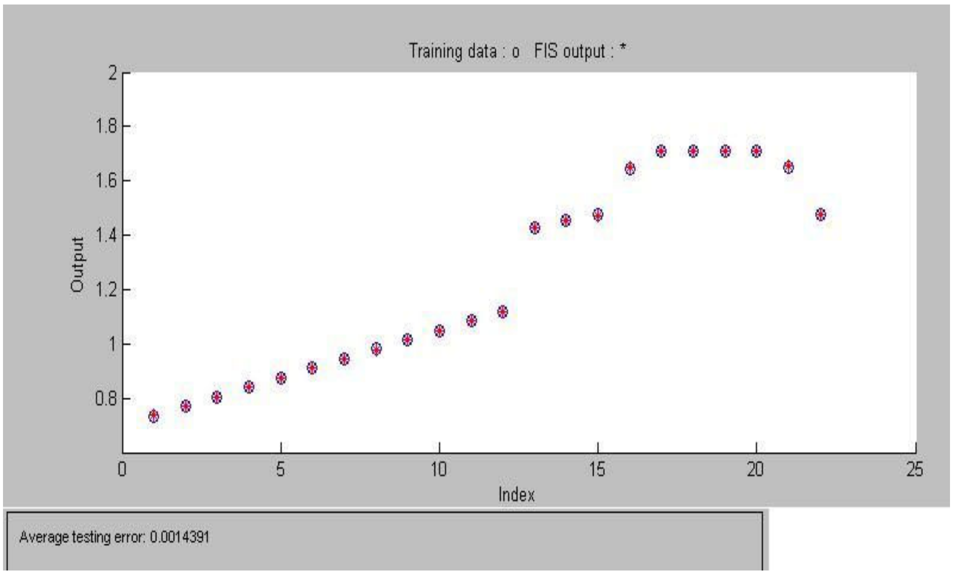
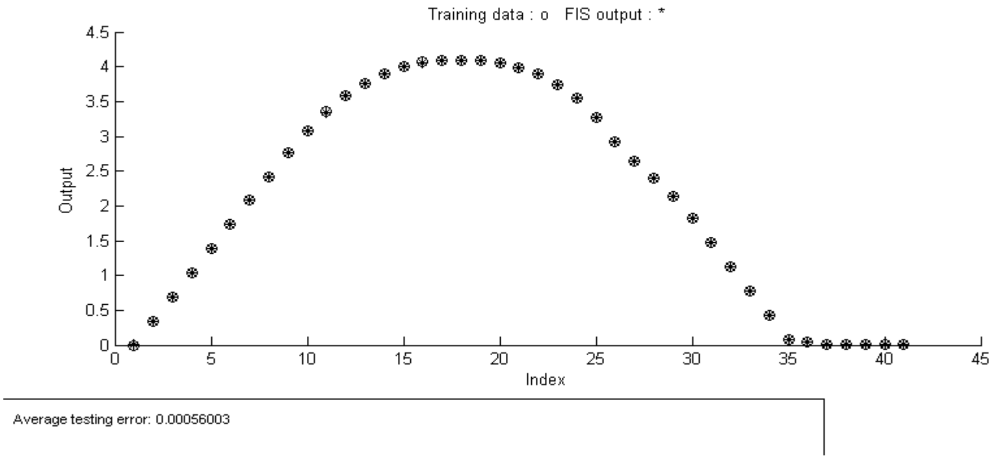


Fig. 8. ANFIS structure used for base case IEEE 14 bus system



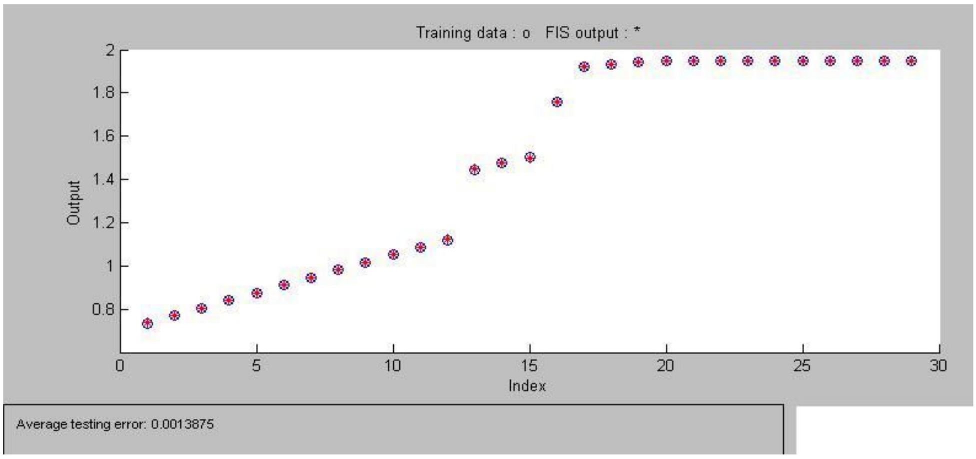
Average testing error: 0.0014391

Fig. 8. ANFIS learned data and its output for base case IEEE 14 bus system



Average testing error: 0.00056003

Fig. 9. ANFIS learned data and its output for case inserting SVC at IEEE 14 bus system



Average testing error: 0.0013875

Fig. 10. ANFIS learned data and its output for case inserting STATCOM at IEEE 14 bus system

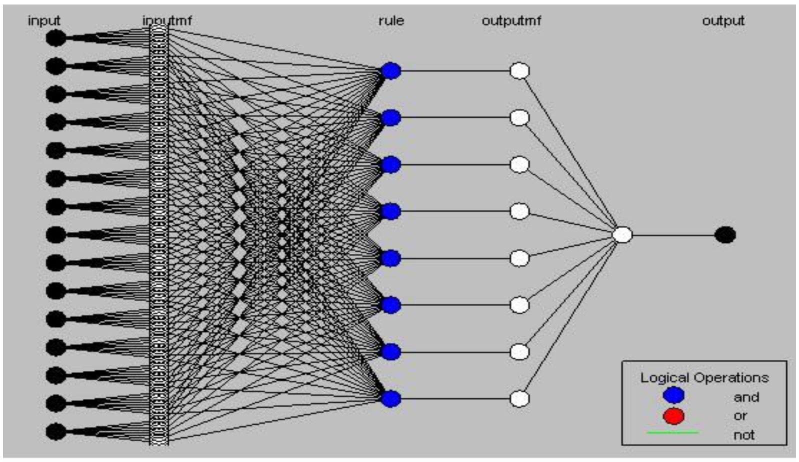


Fig. 11. ANFIS structure used for IEEE 14 bus system including SVC(STATCOM)

The above procedure reapeted for IEEE 14 bus test sytem with insertin SVC and STATCOM . Result of the ANFIS Network is shown at the Fig. 9 and Fig.10 respectively. Also the structure of the new ANFIS network that includes SVC(STATCOM) added input data is shown at Fig.11. The added input contains suseptance of SVC for Trying with SVC and STATCOM current for doing with STATCOM.

5. Conclusion

The results presented in this paper clearly shows how SVC and STATCOM can be used to increase system loadability in practical power systems. Based on simulation results obtained in the paper can conclude that, both SVC and STATCOM can increase system loadability or margin to voltage collapse.

Also , using of ANFIS network for power system as an indicator for loading paprameter estimation introduced. The simulation results indicate that appling ANFIS network in large scale power system for situation awareness or loading condition monitoring produces efficient and reliable response. ANFIS on line ouput performing make it suitable for critical operational conditions such as stall to prone networks.

6. Acknowledgment

This research project have been supported by Islamic Azad University Tehran South-Branch. So the authors make great thanks form research deputy for found and performing good research atmosphere.

References

[1] L.H.FINK, editor, proc.Bulk Power System Voltage Phenomena III-Voltage Stability and Security, ECC Inc., Fairfax, VA, August 1994.

[2]Y.Mansour, editor," Suggested techniques for voltage stability analysis" technical report 93TH0620-5PWR,IEEE/PES,1993.

[3] P.Kundur, editor," Voltage stability assessment, procedures and guides," technical report second draft, IEEE/PES, Power System Stability Subcommitee, 1997

[4] I.Dobsson and II.D.Chiang,"Towards a theory of voltage collapse in electric power systems, " Systems & Control Letters, vol.13 1989,pp.253-262

[5] C.A.Canizares, F.L.Alvardo, C.L.Demarco, I.Dobson, and W. F. Long," Point of collapse methods applied to ac/dc power systems," IEEE Trans. Power System, vol.7, no.2 ,May 1992,pp.673-683

[6] J.Lu, C.w.Liu, and J.S.Thorp," New methods for computing a saddle node bifurcation point for voltage stability analysis," IEEE Trans. Power Systems, vol.10,no.2,May 1995,pp.978-989.

[7] J.Glover, M.Sarma, *power system analysis and design*. PWS publishers, 1987.

[8] L.A.S.Pilloto, W.W.Ping, A.R.Carvalho, A.Wey, W.F.Long, F.L.Alvardo, C.L.Demarco, and A. Edris, "Determination of needed FACTS controllers that increase asset utilization of power system," IEEE Trans. Power Delivery, vol. 12, no.1, January1997, pp.364-371.

[9] Y.Mansour, W.Xu, F.Alvardo, and C.Rinzin,“ SVC placement using critical modes of voltage instabillity,“ IEEE Trans. Power systems, vol. 9, no.2, May 1994, pp.757-763.

[10] Z.T.Faur and C.A.Canizares,“ Effects of FACTS devices on system loadability,“ Proc. North American Power Symposium, Bozmen, Montana, October 1995,pp.520-524.

[11] L.Gyugi," Power electronics in electric utilities: Static Var Compensators," Proceedings of the IEEE, vol. 76, no. 4, April 1988, pp.483-494.

[12] C.A.Canizares,“ Conditions for saddle- node bifurcations in ac/dc power systems," Int. J. of Electric Power & Energy Systems ,vol. 17,no. 1 February 1995 , pp.61-68.

[13] C. A.Canizares and F.L.Alvardo," Point of collapse and continuation methods for large ac/dc systems,“ IEEE Trans. Power Systems , vol. 8 , no. 1, February 1993 , pp.1-8.

[14] Nemat-Talebi, M. Ehsan, S.M.T. Bathaee "An Efficient Power Injection Modeling and Sequential Power Flow Algorithm for FACTS Devices" IEEE SOUTEASTCON 2004, USA.

[15] N. Talebi, M. Ehsan, S.M.T. Bathaee" Effects of SVC and TCSC Control Strategies on tatic Voltage Collapse Phenomena" IEEE SOUTEASTCON 2004, USA.

[16] E. m. Yap, M. AL-Dabbagh, S. K. Kapuduwage, T. O. Maung, N. Talebi "HVDC AND FACTS For improved power delivery through long transmission lines" PES Durban 2005.

[17] N. Talebi, J.Karamdel, A. Farrokhi " Inverse Action of Series Connected FACTS Devices During Voltage Collapse Phenomena" Pelincec 2005, Poland.

[18] N. Talebi, J. Karamdel, A. Farrokhi " Effects of Shunt and Series Connected FACTS Devices on Static Voltage Collapse Phenomena" International Seminar on Power Transmisson Research and Interests , CPRI 2005, Banglore, India.

[19] Nemat-Talebi , M. Shafiee , B. Subramaniam, J. Karamdel " Limit Induced Bifurcation Due to Series Connected FACTS Devices During Voltage Collapse Phenomena" ICIIS 2006, Kandy, Sri Lanka.

[20] K. L. Du and M.S.N. Swamy "neural network in softcomputing framework" Springer 2006.

{21] L. Rutkowski "Flexible neuro fuzzy systems" Kluwer Academic Press 2004.

[22] V. Duraisamy and et al "neuro fuzzy schemes for fault detection in power system transformer" Applied Soft Computing, no 7, 2007.