TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 5, October 2020, pp. 2665~2673
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i5.15605

FLC based on static var compensator for power system transient stability enhancement

Mojeebalrhman M. A. Hassan[1], Xiuyun Sun[2], Abdelrahim Ate[3]
[1,3]Faculty of Graduate Studies, Al-Neelain University, Sudan
[2,3]School of Mechanical and Electrical Engineering, Dezhou University, China

Article Info

Article history:

Received Jan 22, 2020
Revised Apr 11, 2020
Accepted Apr 25, 2020

Keywords:

Fuzzy logic
Power system
SVC
Transient stability

ABSTRACT

Transient Stability is the capability of a system to be able to return to its normal state after experiencing large disturbances. The static var compensator (SVC) is a shunt device of the flexible AC transmission systems (FACTS) family using power electronics to improve transient stability in power system. For the SVC control, it is usually used a PI controller, although PI controller is simpler and cheaper but not suitable when power system is subjected to transient stability since power system become non-linear system. In order to overcome this problem, the PI controller combined with Fuzzy controller is designed. Two types of faults were considered for this study to examine the effect of the fuzzy-SVC controller on system transient stability, the proposed fault types are single line to ground fault and three lines to ground fault. The performance and behavior of the designed fuzzy controller compared with that of the conventional PI controller in term of terminal voltage, rotor angle, and transmission line active power.

Corresponding Author:

Abdelrahim Ate,
School of Mechanical and Electrical Engineering,
Dezhou University,
Dezhou, Shandong, 253023, P.R. China.
Email: wadalroob@gmail.com

1. INTRODUCTION

The power system consists of generating power plants, transformers, transmission lines and loads. With the increasing demand for electrical energy the transmission lines become more loaded than their limits [1]. As a result of this overload, the transient stability issue appeared [2]. Transient stability is the capability of a system to be able to return to its normal state after experiencing large disturbances such switching on-off lines and faults [3, 4]. In recent decades, devices under the term FACTS have emerged, which have greatly helped improve the stability of power systems by controlling system voltage [5]. These devices have several forms, and some are connected in series with a line and the others are connected in shut [6]. In this paper the shunt type like static var compensator (SVC) is discussed.

Recently, the fuzzy logic controller (FLC) has attracted many researchers in the field of stability of electrical power systems, due to its ease of design and capability of dealing with uncertainty and imprecision in system parameters [7]. The last few years have seen numerous papers being published applying fuzzy control to achieve better results in a wide array of power system tasks, and some of these papers are below:

Author C. Udhyashankaret [8] published a paper entitled “Transient Stability Improvement in Transmission System using SVC with fuzzy logic control,” In this paper have presented the model of static var compensator (SVC) with the combination of PI and fuzzy controller. The proposed model has been tested on tow generators three bus's system. The simulation results showed that the combined PI and Fuzzy based SVC controller gave better performance compared with the conventional controller (PI controller).

N. A. Arzeha [9] published a paper which deals with the "Fuzzy-based static var compensator for Damping Power System Disturbances". Here, one of the methods in SVC implementation based on a simple fuzzy logic combined with the conventional Takagi-Sugeno type of fuzzy controller was utilized implementation in of the SVC. The Simulation is done in MATLAB software to perform its effectiveness in damping oscillation after being subjected to a three-phase fault. The system implemented with the F-SVC controller showed better performance compared to conventional PI-SVC controller.

B. Lahshmananayak [10] published a paper which deals with "Reactive Power Control in Long Transmission Line". In this paper, the operating principle and modeling of FC-TCR type static var compensator and the basic study of fuzzy logic controller were demonstrated. Fuzzy Logic Controller was designed to achieve the firing angles for SVC such that it maintains a flat voltage profile. The use of fuzzy logic has facilitated the closed loop control of system, by designing a set of rules that decides the firing angle given to SVC to attain the required voltage.

P. R. Sharma [11] published a paper in which a study about "Fuzzy Based SVC Auxiliary Controller for Damping Low Frequency Oscillations in a Power System" was discussed. In this paper, the operating principle and modeling of FC-TCR, type static var compensator and the basic study of fuzzy logic controller were discussed. The simulations were carried out in MATLAB/Simulink for two area four generators systems and showed the results about the effectiveness of fuzzy logic auxiliary controller over conventional PI controller in damping low frequency oscillations at high power transfer level and severe disturbances conditions.

Ibrahim Mansour [12] published a paper which deals with a study of "Fuzzy Logic Control of SVC to Improve Transient Stability of Ac Power Systems" This paper presents the simple study of the most popular FACTS devices, i.e., shunt (SVC, STATCOM), series (SSSC) and series shunt (UPFC) and also describe the principle of SVC and the basic study of fuzzy logic controller with its basic three steps. It was concluded the proposed new controller is compared with a PI regulator in terms of steady-state and dynamic response and the simulation results point out the better performances of our controller.

In this paper discussed one of the methods in SVC implementation based on a fuzzy logic combined with the conventional (PI) controller. The PI controller incorporated with Fuzzy logic for a higher performance. The fuzzy-SVC controller is implemented on a 2-generators 3-bus system. The simulation model is done by MATLAB software. The effectiveness of the system implemented with the Fuzzy-SVC controller is compared with the system implemented with the conventional PI-SVC controller.

2. RESEARCH METHOD

2.1. Static var compensator

The static var compensator (SVC) is a shunt device of the flexible AC transmission systems (FACTS) family using power electronics to control power flow, regulate voltage and improve transient stability in power system [13]. The SVC is controlled the shunt susceptance (B) which regulates the system voltage by inject or absorb reactive power from the power system. When the voltage is low The SVC will generate reactive power and when the voltage is high it will absorbs reactive power [14]. By switching the capacitor banks and inductor banks can be controlling the variation of the reactive power [15]. Capacitor bank is switched on-off by Thyristor Switched Capacitor (TSC). The reactor is switched on-off by thyristor controlled reactor (TCR) [16].

The architecture of the SVC and its insertion in a power system is shown in Figure 1. The architecture of SVC is consists of step down transformer, a voltage regulator that determine susceptance (B), TCR unit, TSC units and a phase locked loop (PLL) for the synchronization with the secondary voltage [12]. The control system consists of:

- A measurement system measuring the voltage to be controlled.
- A voltage regulator that uses the voltage error (difference between the measured voltage (Vm) and the reference voltage (Vref)) to calculate the SVC susceptance needed to keep the system voltage at desired level.
- A distribution unit that calculates the TSC that must be switched on-off, and determines the firing angle (α) of TCR.
- A synchronizing unit using a PLL synchronized on the secondary voltages and a pulse generator that send adequate pulses to the thyristors [17].

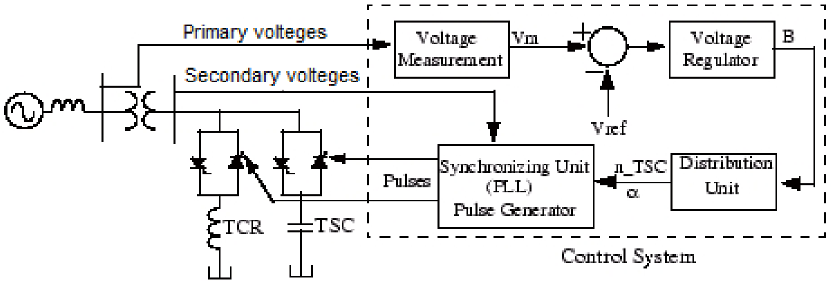

Figure 1. SVC schematic diagram

2.2. Fuzzy logic SVC control

Conventional SVC controller is using a PI controller. At present, the PI controller is simple in structure, easy to design and low cost. Thus, PI controller has been utilized most widely in industrial application currently [18]. However, its drawbacks where it will fail when the controlled object is highly nonlinear and uncertain has made it less effective in power system network application. In order to overcome this problem PI controller combined with Fuzzy controller is designed [12, 18]. There are two types of FLC which are Mamdani and Takagi-Sugeno [19]. In this paper the Takagi-Sugeno type is been used. The proposed controller combines the fuzzy logic controller with PI controller. The FLC is in place of the integral term while the proportional term is kept unchanged. The schematic diagram of the Fuzzy-SVC controller is shown in Figure 2.

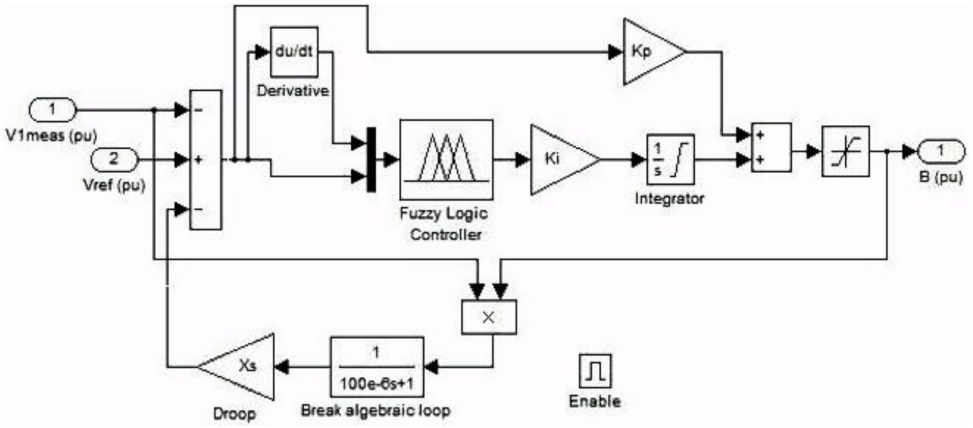

Figure 2. Fuzzy-SVC controller

2.2.1. The membership function

There are several types of MFs such as triangular, trapezoid, Gaussian and polynomial. For the Fuzzy-SVC, the triangular type of MF is been used [20]. To fuzzify inputs three fuzzy sets were used: positive (P), zero (Z) and negative (N). In this paper Fuzzy-SVC controller is designed with tow inputs and single output. Input 1 shown in Figure 3 is error (e) that is a difference between measuring voltage (v_{meas}) and reference voltage (v_{ref}), input 2 shown in Figure 4 is a change of error (de/dt). Takagi-Sugeno has two types of output MF which are constant and linear [21]. As for this controller, linear type of output MF is used.

2.2.2 Fuzzification

The fuzzification operation is concerned with converting of non-fuzzy or crisp input values into a fuzzy quantity.

2.2.3 The inference

The task of the inferencing process is to map the fuzzified inputs (as received from the fuzzification process) to the rule base, and to produce a fuzzified output for each rule [5]. The relation between the inputs and output of FLC is defined by a set of rules [22]. The form of rule in a Takagi-Sugeno fuzzy model is:

If Input 1 = x and Input 2 = y, then Output is: $z = ax + by + c$

There are several methods used to define the rules, such as trial-and-error, offline simulation, and experiencing. When system dynamics are not known or are highly nonlinear it is considered the trial-and-error and experiencing is the most appropriate method to generate rules [9]. For the Fuzzy-SVC controller, the fuzzy inference of prod-probor is used. The prod-probor inference method is similar to AND – OR logical operation. The typical rules are:
Rule 1: If voltage error (e) is N AND change of error (de) is N, then the output is N.
Rule 2: If voltage error (e) is N AND change of error (de) is Z, then the output is N.
Rule 3: If voltage error (e) is N AND change of error (de) is P, then the output is Z.
Rule 4: If voltage error (e) is Z AND change of error (de) is N, then the output is N.
Rule 5: If voltage error (e) is Z AND change of error (de) is Z, then the output is Z.
Rule 6: If voltage error (e) is Z AND change of error (de) is P, then the output is P.
Rule 7: If voltage error (e) is P AND change of error (de) is N, then the output is Z.
Rule 8: If voltage error (e) is P AND change of error (de) is Z, then the output is P.
Rule 9: If voltage error (e) is P AND change of error (de) is P, then the output is P.
The two inputs and single output of FLC will result in 9 rules [8]. Table 1 shows the rule base of the FLC.

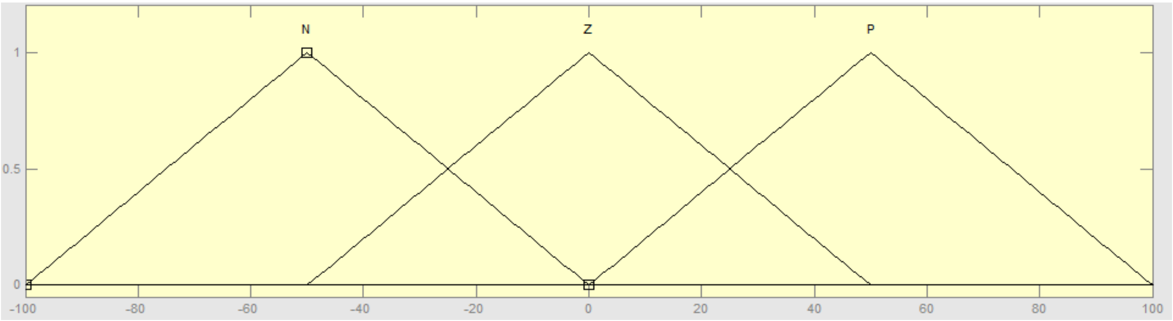

Figure 3. Membership function of input 1 (error (e))

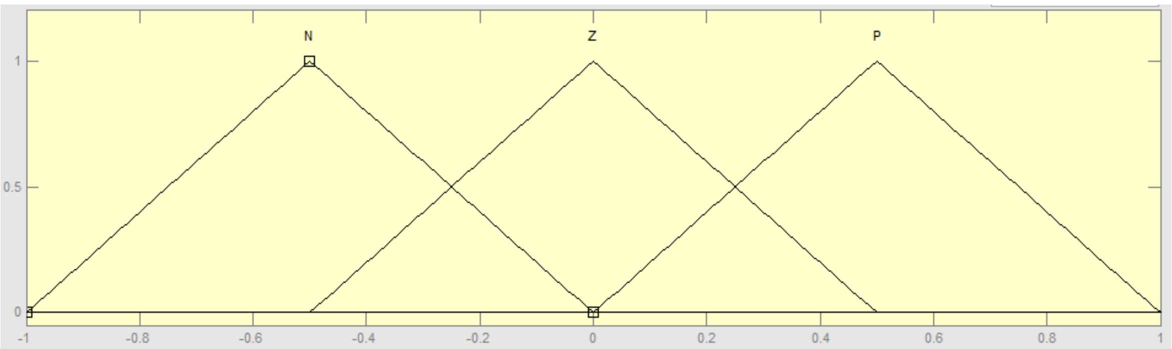

Figure 4. Membership function of Input 2 (change of error (de/dt))

Table 1. Membership rules for controller

e de/dt	N	Z	P
N	N	N	Z
Z	N	Z	P
P	Z	P	P

where, N = Negative, Z = Zero, P = Positive

2.2.4. Defuzzification

The defuzzification process means convert the output of the fuzzy rules into a non-fuzzy numerical output. To compute the output of fuzzy logic control, the weighted average method is used.

$$Output = \frac{\sum_{i=1}^{N} \omega_i Z_i}{\sum_{i-1}^{N} \omega_i}$$

ω_i is the firing strength of the rule that weighted the output level. The output of fuzzy controller is the control signal that will apply to the firing angle control units.

2.3. System testing

System testing includes two generators (G1 and G2) and 3 buses. Generator 1 (G1) is a 1000 MVA connected to a resistive load centre 5000 MW through a long 500 kV, 700 km transmission line. The load centre is supplied by the remote generation generator 2 (G2) 5000 MVA. A 200 MVAR SVC is implemented at the centre of the transmission line to maintain the system stability after faults occurrence [23]. The test system is shown in Figure 5.

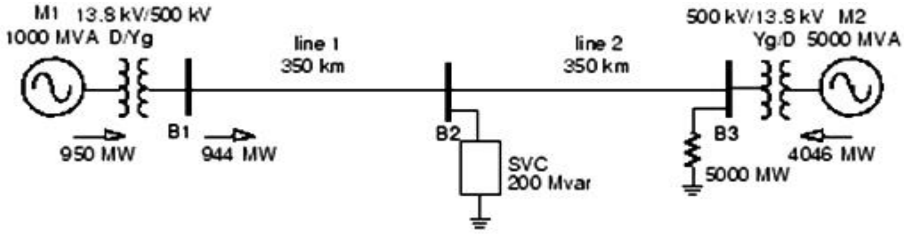

Figure 5. Single line diagram of 2-generator 3-bus test system

3. RESULTS AND ANALYSIS

This section presents and analyzes simulation results obtained on the two generators three bus's tested system. The tested system is investigated under two types of faults, single line to ground fault and three lines to ground fault, Figure 6 shown the tested system. Numerous graphs showing the performance and behavior of the system in term of terminal voltage, rotor angle, and transmission line active power have been included to explicate the analysis.

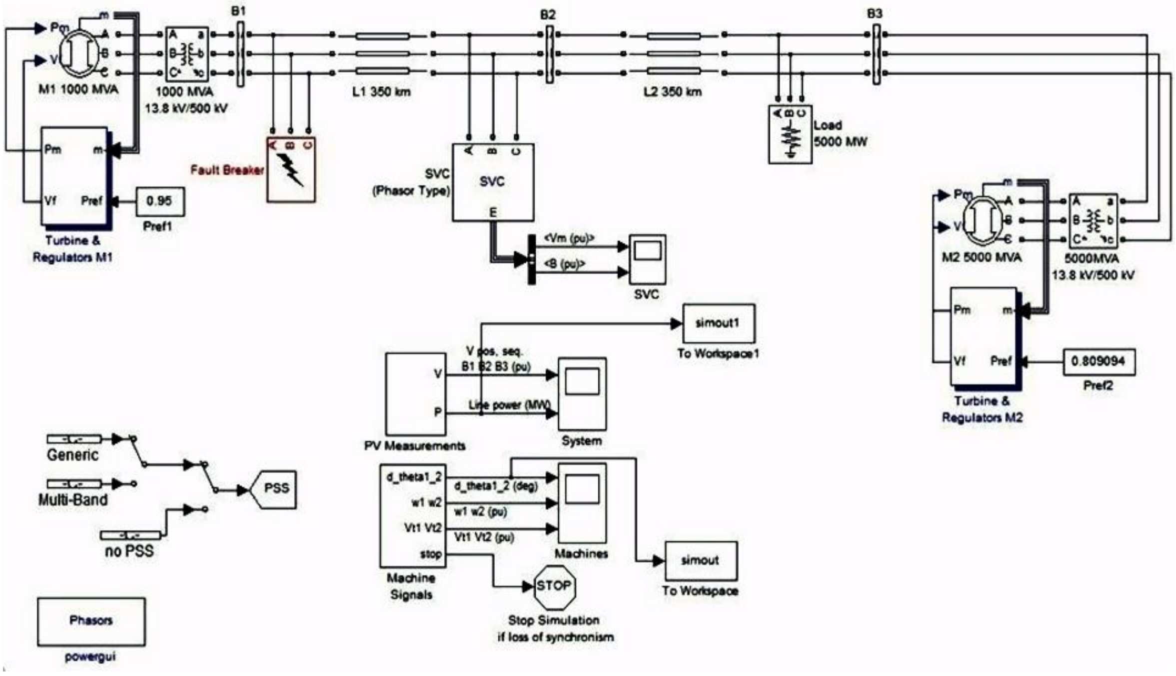

Figure 6. Single line diagram of 2-generator 3-bus test system

3.1. Single line to ground fault case

A single-phase fault occurred at bus 1 for 0.6 second from t1= 0.2 second to t2 = 0.8 second. From Figure 7, Figure 8 and Figure 9 can observe that the effect of the SVC with the proposed FLC controller and PI controller approximately is same. PI controller provides not bad performance because the fault level is not large that mean the nonlinearity it is not high [24].

3.2. Three line to ground fault case

Now the three line to ground fault was applied to the system at bus 1 for 0.6 second from t1 = 0.2 second to t2 = 0.8. From Figures 10-12 can be notice that the PI-SVC controller cannot provide satisfactory performance compared to the Fuzzy-SVC controller because the nonlinearity of the system becomes very high due to increasing in fault level (from single line to three line to ground fault). The simulation results shown above clearly demonstrate that system was implemented with Fuzzy-SVC controller gives less oscillation and fast stability compared to the conventional PI-SVC controller [25]. There has been amount of paper done to develop new controllers for the SVC this works reached to the same results in this paper. But what distinguished the proposed controller in this paper it is supported system for long time of fault duration it is 0.6 second compared to 0.4 second in other paper due to substantial change made to the proposed controller in term of the rules and membership functions.

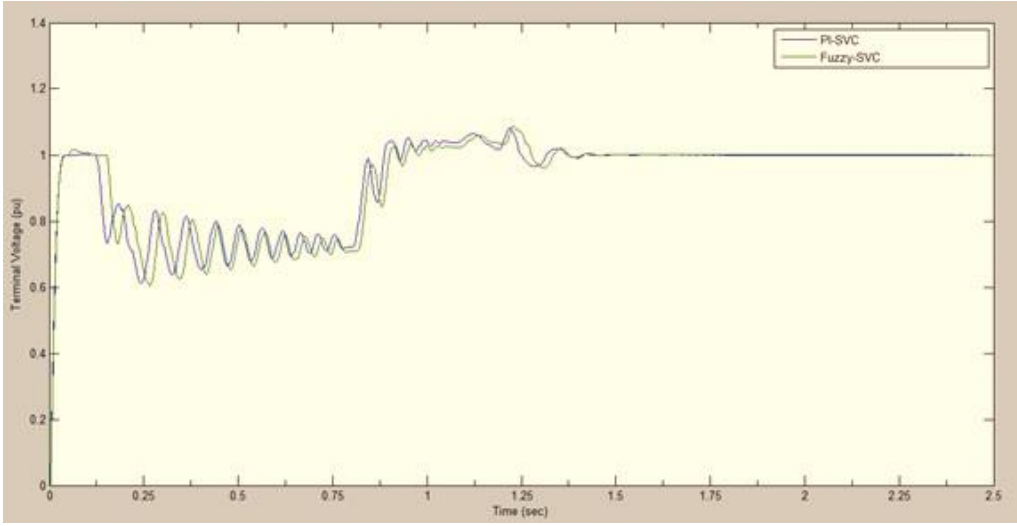

Figure 7. Terminal voltage of the system when single line to ground fault is applied

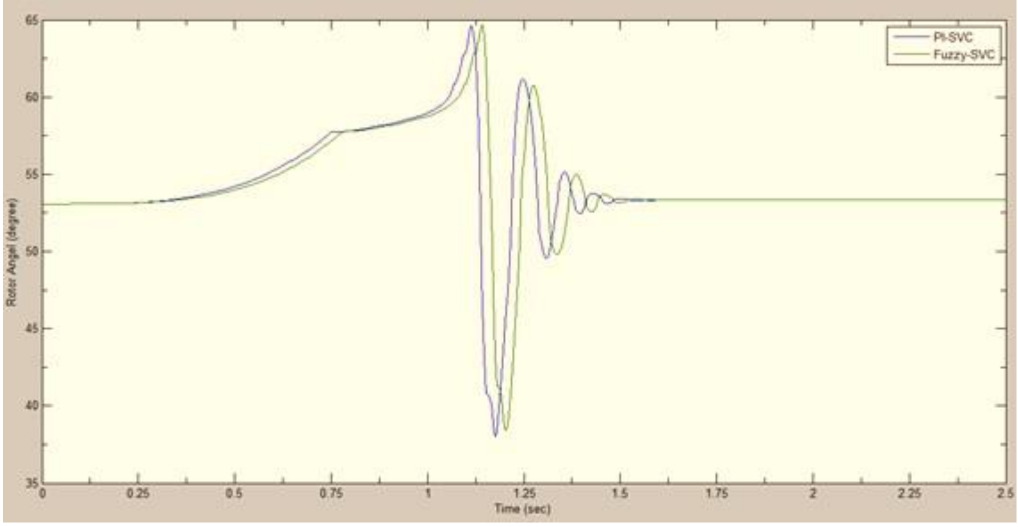

Figure 8. Difference of rotor angle of generator when single line to ground fault is applied

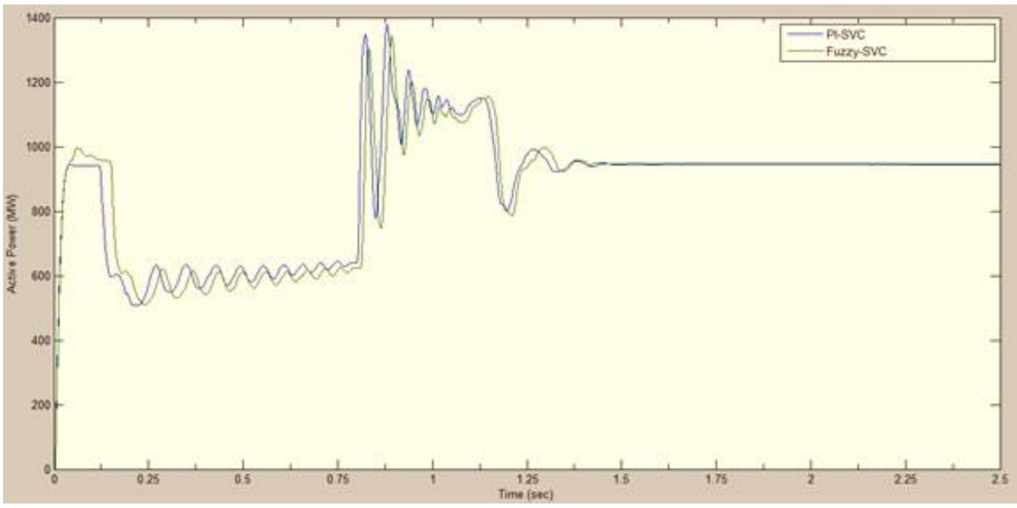

Figure 9. Transmission line active power of the system when Single line to ground fault is applied

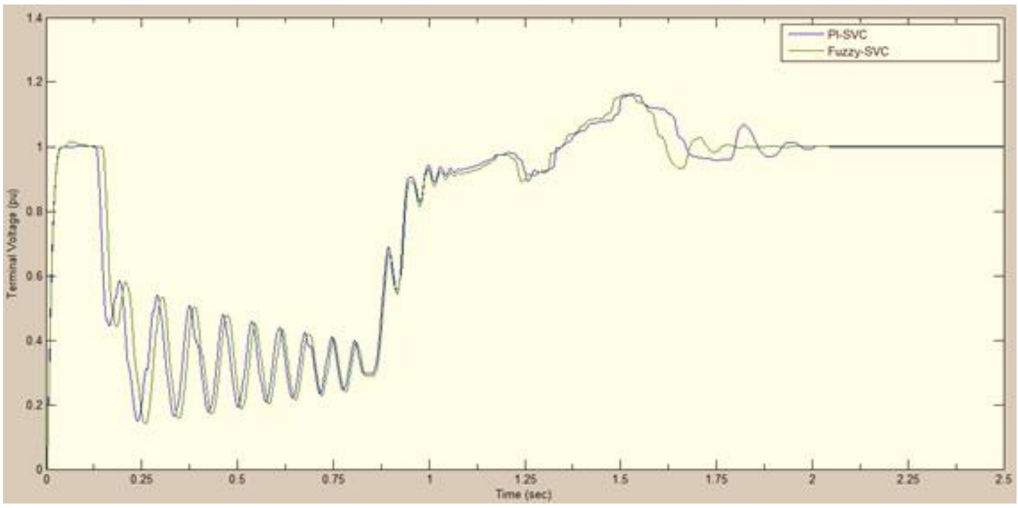

Figure 10. Terminal voltage of the system when three line to ground fault is applied

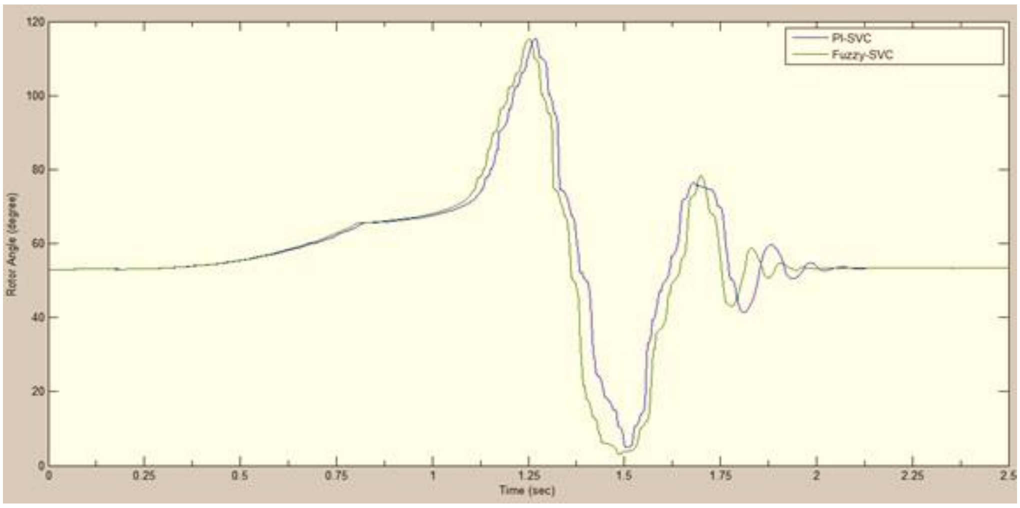

Figure 11. Difference of rotor angle of generator when three line to ground fault is applied

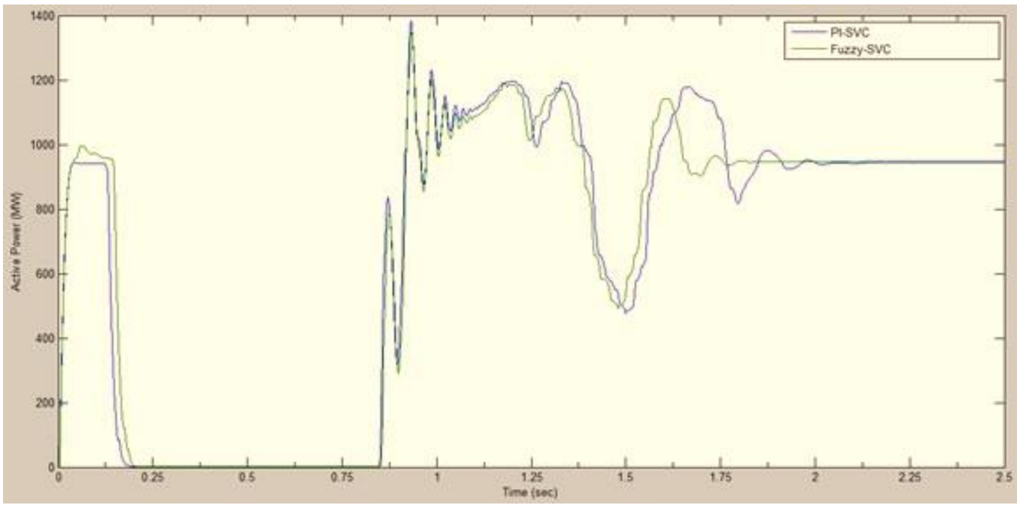

Figure 12. Transmission line active power of the system when three line to ground fault is applied

4. CONCLUSION

In this paper, dynamic behavior of two machine system installed with SVC is investigated after subjected system to single line to ground fault and three lines to ground fault. To enhance the transient stability of the system Fuzzy-SVC controller is proposed. For Fuzzy logic controller the difference between measuring voltage (vm) and reference voltage (vref) i.e. error (e) is taken as input, while susceptance (B) is taken as output. Various parameters like rotor angle deviation, terminal voltage of system and transmission line active power are observed. Simulation results show that the Fuzzy-SVC controller provides good performance as compared to conventional PI-SVC controller.

ACKNOWLEDGEMENTS

We thank the anonymous referees for their useful suggestions, As well to Alneelain university and Dezhou university for the support.

REFERENCES

[1] Padrón S., Medina J. F., Rodríguez A., "Analysis of a pumped storage system to increase the penetration level of renewable energy in isolated power systems. Gran Canaria: A case study," *Energy*, vol. 36, no. 12, pp. 6753–6762, 2011.

[2] J. M. Gonzalez, C. A. Canizares and J. M. Ramirez, "Stability modeling and comparative study of series vectorial compensators," *IEEE Transactions on Power Delivery*, vol. 25, no. 2, pp. 1093-1103, 2010.

[3] Mohammed Mynuddin, et al., "Stability Study of Power System," *International Journal of Energy and Power Engineering*, vol. 4, no. 2, pp. 43-50, 2015.

[4] Muhammad Yousaf Ali Khan, Umair Khalil, Hamayun Khan, "Power Flow Control by Unified Power Flow Controller," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3900-3904, 2019.

[5] Amir Movahedi, Abolfazl Halvaei Niasar, Gevork B. Gharehpetian, "LVRT improvement and transient stability enhancement of power systems based on renewable energy resources using the coordination of SSSC and PSSs controllers," *IET Renewable Power Generation*, vol. 13, no. 11, pp. 1849-1860, 2019.

[6] Gandoman, et al., "Review of FACTS technologies and applications for power quality in smart grids with renewable energy systems," *Renewable and Sustainable Energy Reviews*, vol. 82, part 1, pp. 502-514, 2018.

[7] Bouzid, et al., " A survey on control of electric power distributed generation systems for microgrid applications," *Renewable and Sustainable Energy Reviews*, vol. 44, pp. 751-766, 2015.

[8] C. Udhyashankar, R. Thottunga, "Transient Stability Improvemennt in Transmission System using SVC with Fuzzy Logic Control," *IEEE international conference on Advances in Electrical Engineering (ICAEEE)*, pp. 1-4, 2014.

[9] N. A. Arzeha, M. W. Mustafa, " Fuzzy-based Static VAR Compensator Controller for Damping Power System Disturbances," *IEEE International Conference on Power Engineering and Optimization Conference (PEDCO)*, pp. 538-542, June 2012.

[10] B. Lahshmananayak and G. Venkataratnam, "Reactive Power Control in Long Transmision Line," *International Conference on Sustainable Energy and Intelligent Systems (SEISCON 2011)*, pp. 427-431, 20-22 July 2011.

[11] Anju Gupta and P. R. Sharma, "Fuzzy Based SVC Auxiliary Controller for damping low frequency oscillations in a power system," *The Next Generation Information Technology Summit (4th International Conference)*, pp. 87-91, 26-67 September 2013.

[12] Ibrahim Mansour, et al., "Fuzzy logic control of a SVC to improve the transient stability of ac power systems," *35th Annual Conference of IEEE Industrial Electronics*, pp. 3240-3245, 2010.

[13] Naveen Singh, Piyush Agnihotri, " Power system stability improvement using FACTS devices," *International Journal of Advance Research and Development*, vol. 3, no. 4, pp. 171-176, 2018.

[14] Siti Amely Jumaat, et al., "A Voltage Improvement of Transmission System Using Static Var Compensator Via Matlab/Simulink," *Indonesian Journal of Electrical Engineering and Computer Scienc*e, vol. 6, no. 2, pp. 330-337, 2017.

[15] Gudaru and D. R. Patil, "An Innovative Transient Free Adaptive SVC in Stepless Mode of Control," *International Journal of Electrical and Computer Engineering*, vol. 5, pp. 458-465, 2011.

[16] Doina Ilisiu and Elena-Daniela Dinu "Modern Reactive Power Compensation for Smart Electrical Grids," *22nd International Conference on Control Systems and Computer Science (CSCS)*, vol. 19, pp. 353-357, 2019.

[17] Ahmed, et al., "Small-Scale Wind Turbine Coupled Single-Phase Self-Excited Induction Generator with SVC for Isolated Renewable Energy Utilization," *5th International Conference on Power Electronics and Drive Systems*, pp. 781-786, 2003.

[18] Ghadimi, "A new hybrid algorithm based on optimal fuzzy controller in multimachine power system," *Complexity*, vol. 21, no. 1, pp. 78-93, 2014.

[19] Nadarajah, et al., "Comparison of PSS, SVC, and STATCOM Controllers for Damping Power System Oscillations," *IEEE Transactions*, vol. 18, no. 2, pp. 786-792, 2003.

[20] John H. Lilly, "Fuzzy Control and Identification," *John Wiley & Song*, Second Edition, 2010.

[21] Kamyar Mehran, "Takagi-Sugeno Fuzzy Modeling for Process Control," Industrial Automation, Robotics and Artificial Intelligence, Third Edition, 2003.

[22] Rishe, Abraham Kandel, "Fifty Years of Fuzzy Logic and its Applications," Studies in Fuzziness and Soft Computing, vol. 326, pp. 1434-9922, 2014.

[23] Roopesh Kumar, Ashish Choubey, "Voltage Stability Improvement by using SVC with Fuzzy Logic Controller in Multi-Machine Power System," *International Journal of Electrical and Electronics Research*, vol. 2, no. 2, pp. 61-66, 2014.

[24] Pradipsinh R. Jadav, Ankit Gajjar, "Design of Fuzzy Logic Controlled SVC For Long Transimiison Line," *International Journal For Technological Research In Engineering*, vol. 3, no. 8, pp. 2347-4718, 2016.

[25] M. G. Hemeida, et al., "Stabilization of a Wind Farm Using Static VAR Compensators (SVC) Based Fuzzy Logic Controller," *Advances in Energy and Power*, vol. 3, no. 2, pp. 61-74, 2015.

BIOGRAPHIES OF AUTHORS

Mojeebalrhman Mohyedeen was born in white nile state, Sudan, in 1991. He received the B.S. degree in electrical engineering from Sudan University of Science and Technology, Khartoum, Sudan in 2014. Now he is preparing for a master's degree

Dr. **Sun Xiuyun** holds a BSc. (2002) in Automation from Ocean University of China, MSc (2005) in Control Theory and Control Engineering from Shandong University and a PhD (2013) in Control Theory and Control Engineering from Nankai University. Her current research deals with Nonlinear System Control and Flight Control Algorithm.

Dr. Abdelrahim Ate holds a BSc. (2002) in control engineering from Alneelain University (Sudan), MSc (2009) in Electrical Engineering from ITS Surabya (Indonesia) and a PhD (2016) in Circuits and System from Dalian University of Technology (China). His current research deals with Control Systems Engineering, Telecommunications Engineering, Computer Engineering and Embedded Systems, Cloud computing, IoT, Electrical Engineering and Electronic Engineering, Nanotechnology and Materials Sciences.