

# FOPID Controlled Shunt Active Filter in IEEE Thirty Bus System with Improved Dynamic Time Response

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## ABSTRACT

This paper aims at improving the dynamic time response of a Wind Energy Conversion System (WECS) connected to IEEE Thirty Bus System (TBS) using Permanent Magnet Synchronous Generator (PMSG) in closed-loop controlled Active Power Filter with Fractional Order Proportional Integral Derivative (FOPID) controller. The objective of the FOPID controller is to reduce the steady state error and Total Harmonic Distortion (THD). The simulation results are presented to find the effectiveness of a shunt active filter using FOPID controller. An Open Loop Thirty Bus System (OLTBS) with a change in load is simulated. The simulation results with Proportional Integral (PI) and FOPID Controller based SAF are compared and the corresponding time-domain parameters are presented. The results indicate that FOPID Controller system has a better response than PI controlled system.

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## 1. INTRODUCTION

The usage for power electronic converters for various industries, commercial sectors and residential applications increases day to day due to their improvement in the technology. These static converters polluting the utility supply due to the harmonics and inter frequency components generated by them. Harmonics have adverse result on the facility system network and lead to excessive heating of neutral conductors, bus bars, lug connections, control and switchgear, which can have an effect on current interrupting capabilities, Circuit breaker nuisance tripping, malfunction of on-board breaker physical science, excessive arcing, improper fuse operation or blown fuse interruption (artificial heating or “skin effect”), Meter, protective relaying, control and other communication and measuring instrumentation devices (including ground fault detection and digital displays). A shunt active filter shown in Fig.1 below is an alternate solution to mitigate harmonics generated by the non-linear loads and also provides reactive support to the system, hence system power factor is improved.

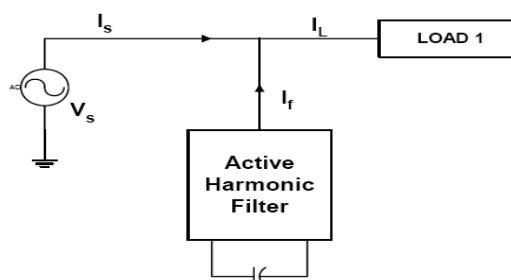


Figure 1. Shunt Active Power Filter block diagram

## 1.1. THEORY OF SHUNT ACTIVE POWER FILTER

The concept of the Shunt Active Filter[1]-[2] is to produce harmonic compensating currents equal in magnitude but opposite in-phase to those harmonics that are present in the electric grid. The standard rules, just like the IEEE 519 limits the harmonics at the entranceway, enforce to limit the harmonic pollution. Passive filters [3] are cannot find the exact solution to the harmonics and poor power factor issue due to their sizes, resonance issues at apart from tuned frequencies, poor performance with variation in input frequency, etc. Fig.2 illustrates the schematic representation of Active Filter.

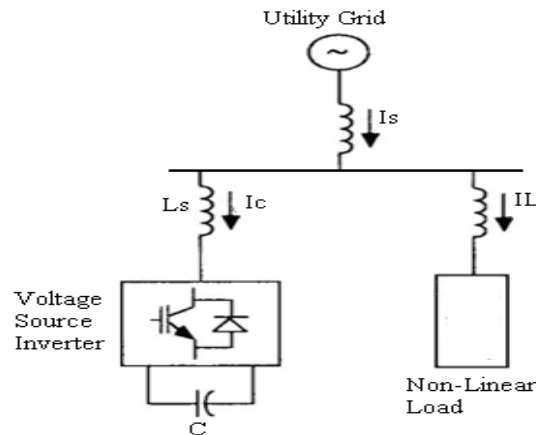


Figure 2. Schematic Representation of Active Filter

The shunt active filters are used to eliminate the unwanted harmonics and compensate fundamental reactive power consumed by nonlinear loads by injecting the compensation currents into the AC lines. Here, the shunt active filter operates as a current source so that it injects harmonic current into the AC system with the same amplitude as that of the load but with an opposite phase. This principle is applicable to a variety of loads. The APF has VSI and a series inductor.

## 1.2. SHUNT ACTIVE FILTER WITH PI /FOPID CONTROLLER

Fig.3 shows the block diagram of the implemented PI/ FOPID control scheme of a shunt active filter. PI/FOPID controller is used to generate switching pulses with the help of the Pulse Width Modulated( PWM) controller. Active Power Filter has a solution to Power Quality (PQ) problems in the distribution network is given by Rudnick [4]. Proportional resonant controlled SAF is an active filter in IEEE TBS with an improved response is given by Anisha [5]. FOPID controlled Interleaved Boost Converter(ILBC) fed SAF is suggested by Ramkumar [6]. A fundamental harmonic components of a load is extracted using Artificial Neural Network and harmonic current is compensated by using discrete fuzzy logic is reported in [7]. Authors in [8] have proposed a 5/5 rule-based Fuzzy Logic Controller (FLC) in combination with indirect current control is applied to the SAF in a single-phase system to improve the power quality. A Hybrid filter is operated as a variable harmonic conductance and eliminates the harmonic distortion in industrial power systems is reported in [9]. Authors in [10] have proposed an enhanced closed-loop current control scheme without using phase-locked loops (PLL), when Distributed Generation (DG) unit is connected to a grid with frequency deviation. In [11], power quality improvement by using a combination of shunt hybrid power filter and thyristor controlled reactor is reported. Digital control of a shunt hybrid power filter has a different scheme of approach such as nonlinear control and optimal control to meet IEEE Std. 519 current harmonic constraints under non-ideal supply condition have been reported in [12] and [13]. In [14], cascaded multilevel inverter for active harmonic filtering in distribution network is reported.

In [15] and [16], resonance control of modular three-level shunt active power filter is proposed and optimization algorithm for selective compensation technique is reported. In [17], predictive harmonic control and its optimal digital implementation for the Modular Multilevel Converter (MMC)-based active power filter are reported. Shunt active power filter based on cascaded transformers coupled with three-phase bridge converters and the experimental design of the adaptive backstepping control technique for single-phase shunt active power filters have been reported in [18] and [19]. Authors in [20] have proposed a Fuzzy logic controller for Grid-connected wind energy conversion system. Optimization of power quality control by using the PI and Fuzzy controller is reported in [21].

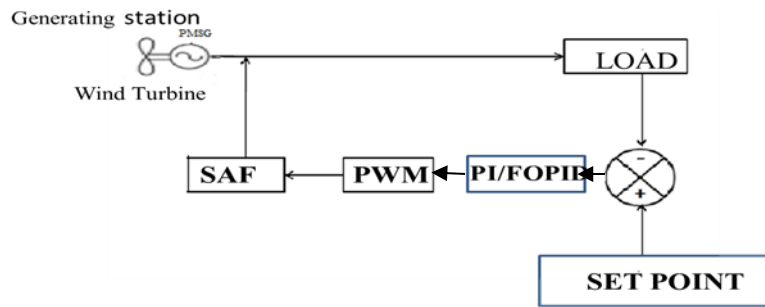


Figure 3. Block diagram of Shunt Active Filter with PI/FOPID controller

The output and inputs of the FOPID controller are related as follows

$$FOPID(s) = K_p + \frac{K_i}{s^\lambda} + K_d s^\mu \text{ --- (1)}$$

Here  $\lambda$  and  $\mu$  are fractions.

The Block diagram of Shunt Active Filter with PI and FOPID controller as shown above in Fig.3. The controller input is an error signal obtained from the reference voltage and the value r.m.s of the terminal voltage measured. Such error is processed by a PI/FOPID controller and the output is given to PWM signal generator. The output PWM signal generator chooses the task of the converter switches.

The literature [1]-[21] do not report the use of SAF for TBS. The comparison of responses of PI and FOPID controlled SAF in TBS is not reported. This work suggests SAF for TBS to improve the dynamic response and to reduce the THD.

**2. IEEE TBS WITH SAF**

The one-line diagram of TBS with SAF[5] is shown in Fig.4. This network has generators, wind buses and lines are modelled as per IEEE Standard TBS data. This transmission line network data for the buses are tabulated in the Appendix-I. In this network, a disturbance, i.e change in load is given in a 27<sup>th</sup> bus and the corresponding dynamic time-domain parameters are measured at that bus.

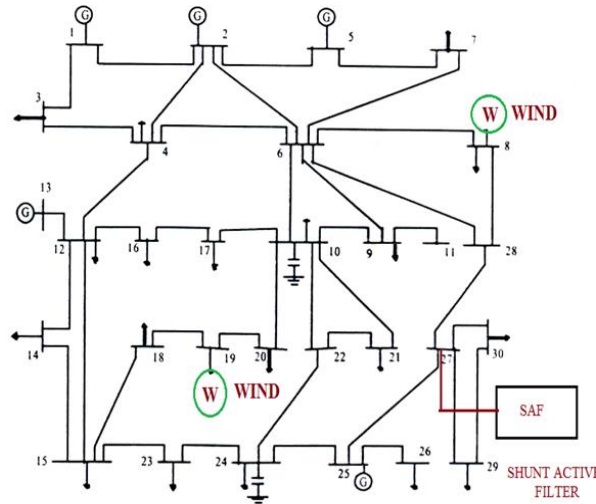


Figure 4. One line diagram of IEEE TBS with shunt active filter

**3. SIMULATION RESULTS**

Open Loop TBS with disturbance is shown in Fig.5. The Voltage at bus-27 of OLTBS is given in Fig.6. and its value is 2000V. RMS voltage at bus-27 of OLTBS is given in Fig.7 and its value is 1420 V. Current at bus-27 of OLTBS is given in Fig.8. Real power at bus-27 of OLTBS is given in Fig.9 and its value is 0.019 MW. Reactive power at bus-27 of OLTBS is given in Fig.10 and its value is 0.022 MVAR. Current Total Harmonic Distortion (THD) at bus-27 of OLTBS is given in Fig.11. The increase in P and Q is due to an increase in voltage.

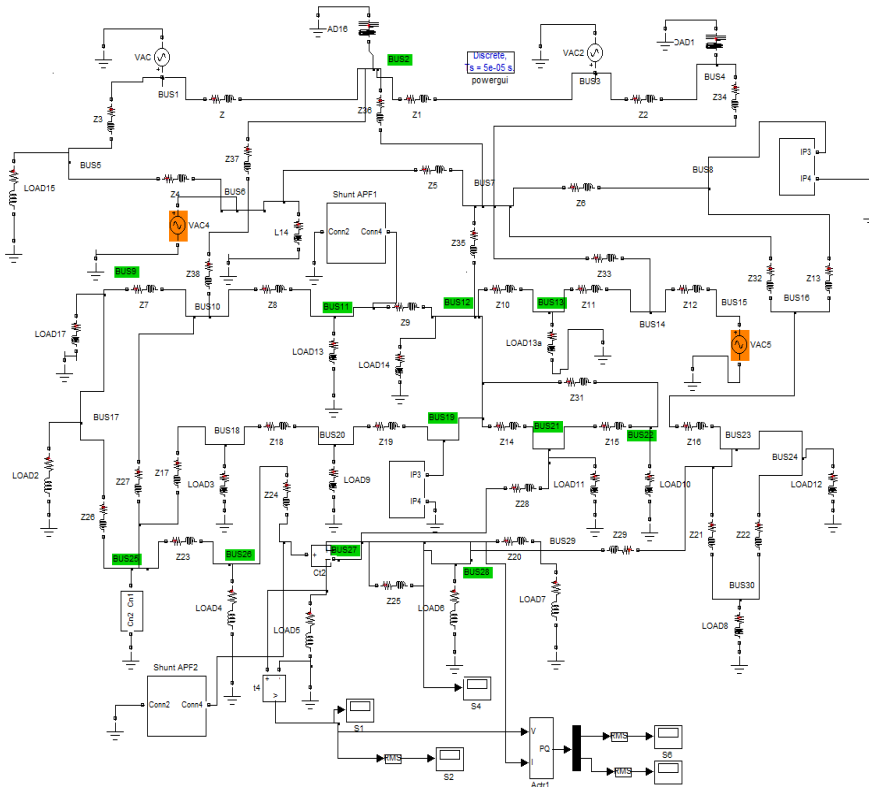


Figure 5. Open Loop TBS with disturbance

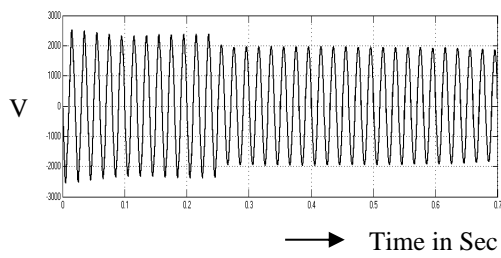


Figure 6. Voltage at bus-27 of OLTBS

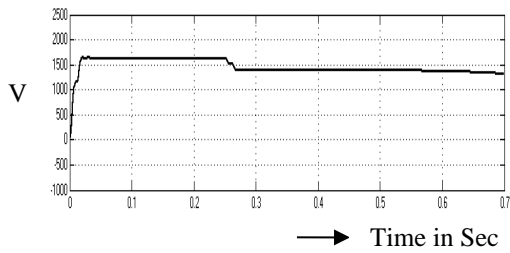


Figure 7. RMS voltage at bus-27 of OLTBS

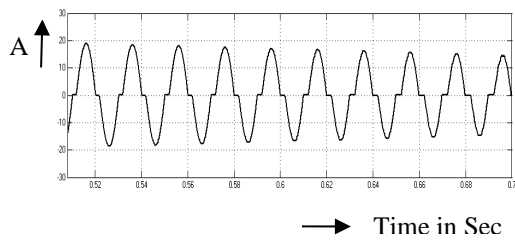


Figure 8. Current at bus-27 of OLTBS

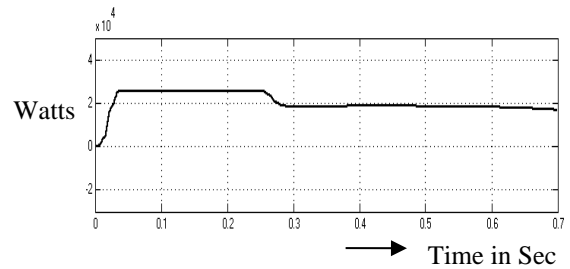


Figure 9. Real power at bus-27 of OLTBS

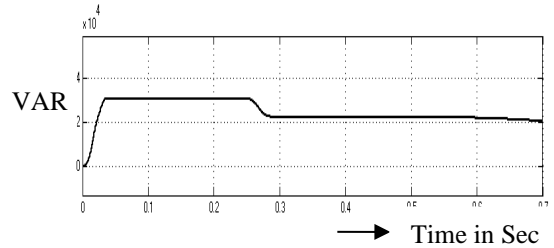


Figure 10. Reactive power at bus-27 of OLTBS

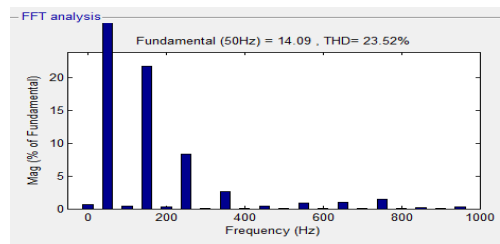


Figure 11. Current THD at bus-27 of OLTBS

Closed loop TBS with PI controller is shown in Fig. 12. The Voltage at bus-27 of Proportional Integral Controlled Shunt Active Filter (PICSAF) is given in Fig. 13 and its value is 2000V. RMS voltage at bus-27 of PICSAF is given in Fig. 14 and its value is 1540 V. Current at bus-27 of PICSAF is given in Fig. 15. Real power at bus-27 of PICSAF is given in Fig. 16 and its value is 0.023MW. Reactive power at bus-27 of PICSAF is given in Fig.17 and its value is 0.027 MVAR. Current THD at bus-27 of PICSAF is given in Fig.18. The increase in voltage is corrected by SAF. This is due to the reduction in pulsewidth.

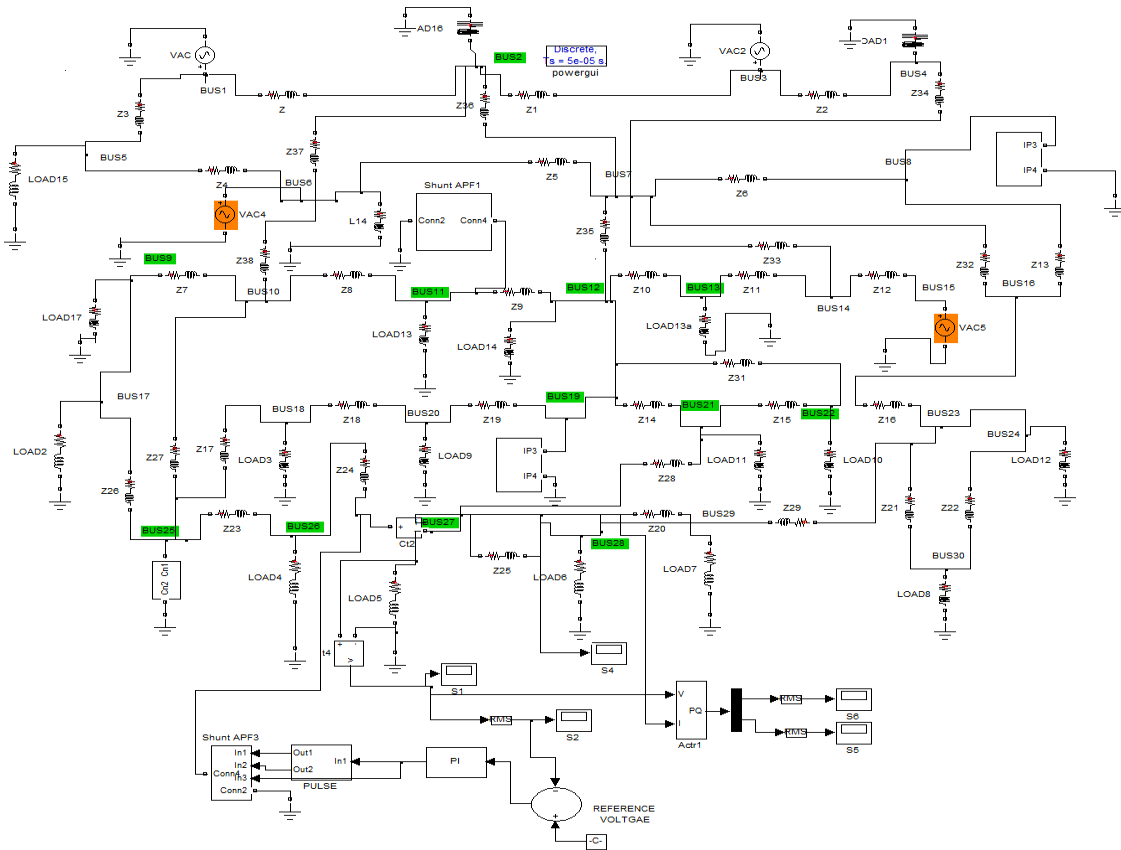


Figure 12. Closed loop TBS with PI controlled SAF

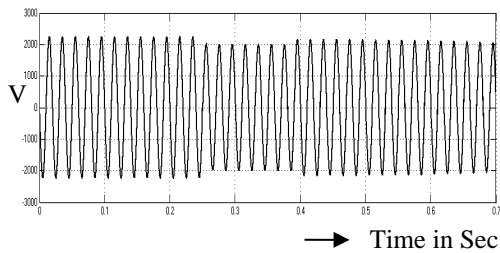


Figure 13. Voltage at bus-27 of PICSAF

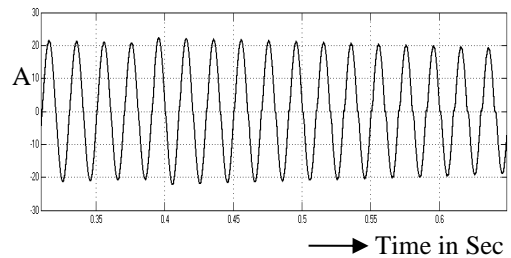


Figure 15. Current at bus-27 of PICSAF

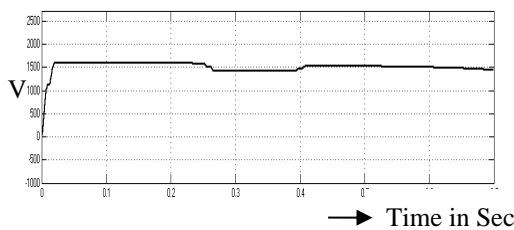


Figure 14. RMS voltage at bus-27 of PICSAF

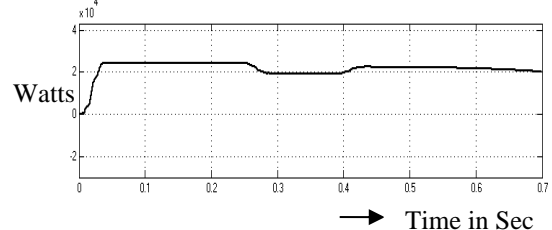


Figure 16. Real power at bus-27 of PICSAF

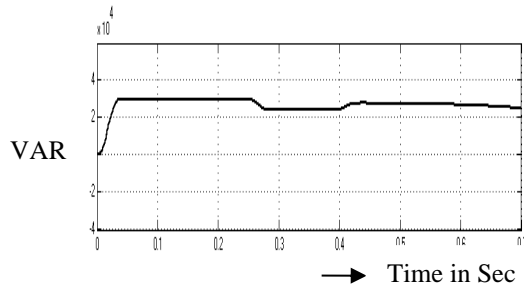


Figure 17. Reactive power at bus-27 of PICSAF

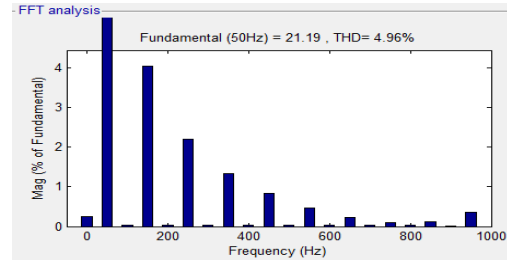


Figure 18. Current at bus-27 of PICSAF

Closed loop TBS with FOPID controller is shown in Fig. 19. The Voltage at bus-27 of Fractional Order Proportional Integral Derivative Controlled Shunt Active Filter (FOPIDCSAF) is given in Fig.20 and its value is 2000V. RMS voltage at bus-27 of FOPIDCSAF is given in Fig.21 and its value is 1545V. Current at bus-27 of FOPIDCSAF is given in Fig.22. Real power at bus-27 of FOPIDCSAF is given in Fig.23 and its value is 0.024MW. Reactive power at bus-27 of FOPIDCSAF is given in Fig.24 and its value is 0.029MVAR. Current THD at bus-27 of FOPIDCSAF is given in Fig.25. It can be seen that the voltage brought back to the original value using FOPIDCSAF.

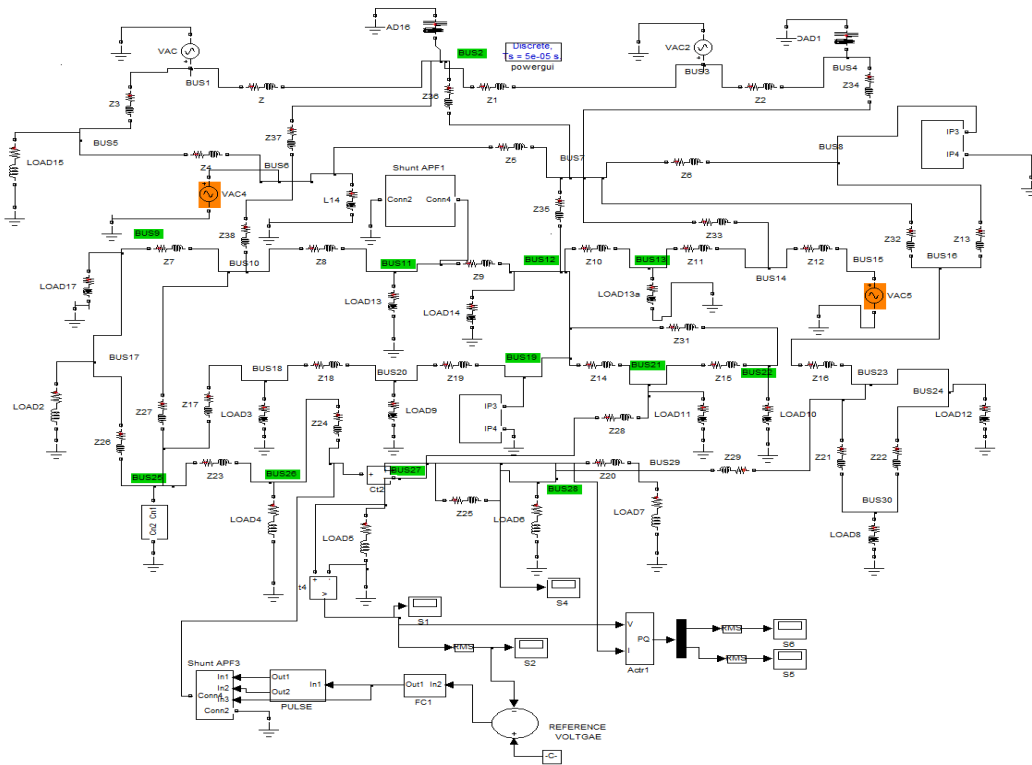


Figure 19. Closed loop TBS with FOPID controlled SAF

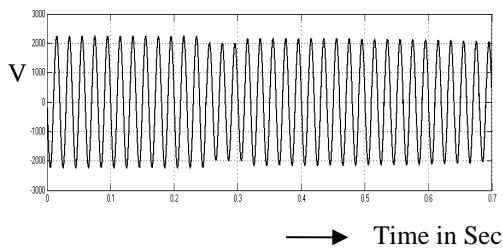


Figure 20. Voltage at bus-27 of FOPIDCSAF

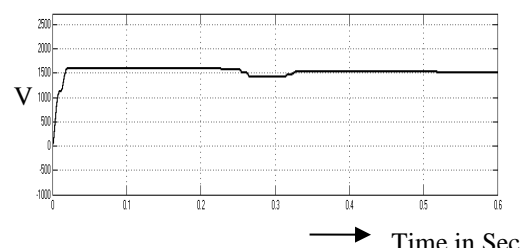


Figure 21. RMS voltage at bus-27 FOPIDCSAF

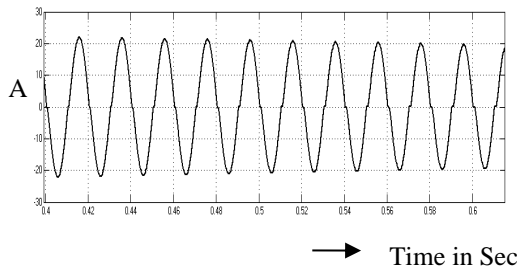


Figure 22. Current at bus-27 of FOPIDCSAF

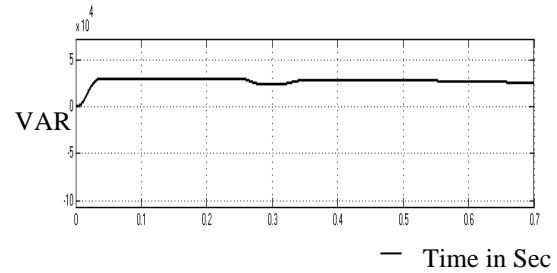


Figure 24. Reactive power at bus-27 of FOPIDCSAF

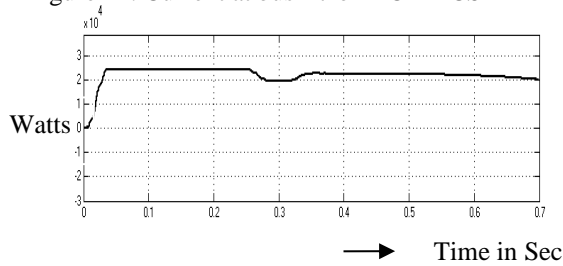


Figure 23. Real power at bus-27 of FOPIDCSAF

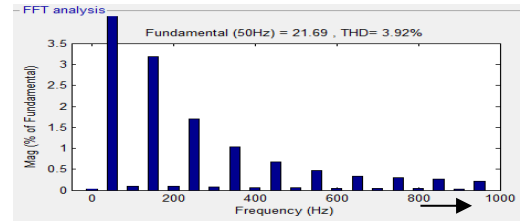


Figure 25. Current THD at bus-27 of FOPIDCSAZZ

Table 1. Comparison of time domain parameters for PICSAF and FOPIDCSAF

Controller	Rise time (sec)	Peak time (sec)	Settling time (sec)	Steady state error (V)
PICSAF	0.26	0.34	0.43	2.4
FOPIDCSAF	0.25	0.29	0.32	1.6

A Comparison of time-domain parameters for PICSAF and FOPIDCSAF is shown in Table.1. By using the FOPID controller, the rise time is reduced from 0.26 to 0.25 sec; peak time is reduced from 0.34 to 0.29 sec; settling time is reduced from 0.43 to 0.32 sec; Steady-state error is reduced from 2.4 to 1.6V. Hence, for closed-loop TBS, FOPIDCSAF is superior to PICSAF. The Dynamic response is also enhanced by using the FOPID controller.

Table 2. Comparison of Current THD for PICSAF and FOPIDCSAF

Controller	Current THD
Open loop TBS	23.52%
Closed loop PICSAF	4.96%
Closed loop FOPIDSAF	3.92%

A Comparison of current THD for PICSAF and FOPIDCSAF at bus 27 is given in Table-2. By using FOPIDSAF, THD is reduced to 3.92% compared to PICSAF. Hence, closed-loop TBS with FOPIDCSAF is superior to PICSAF.

#### 4. CONCLUSION

Thirty bus systems in closed-loop are simulated and the results with PI and FOPID are presented. The steady-state error is reduced from 2.4 V to 1.6V. The settling time is reduced from 0.43 seconds to 0.32 seconds. Therefore FOPID based active filter may be a viable alternative to the existing controller. The reduction in settling time and steady-state error is very high in the case of FOPID controller system. The disadvantage of FOPIDCSAF is that it is not suitable for nonlinear systems.

The present work deals with the investigation of TBS. The improvement in power quality of TBS using Fuzzy controlled SAF will be done in the future.

**APPENDIX-I**  
**LINE DATA AND LOAD DATA**

BUS NO	VOLTAGE	LOAD IMPEDANCE		BUS NO	LINE IMPEDANCE	
		RESISTANCE	INDUCTANCE		RESISTANCE	INDUCTANCE
bus 1	6.3kv	-	-	bus 1-2	1Ω	30mH
bus 2	-	10Ω	100mH	bus 2-5	3Ω	38mH
bus 3	6.3kv	-	-	bus 5-7	6 Ω	40mH
bus 4	-	85Ω	120mH	bus 3-1	13 Ω	37mH
bus 5	-	200Ω	300mH	bus 4-2	15Ω	30mH
bus 6	6.3kv	-	-	bus 6-2	23 Ω	26mH
bus 7	-	125 Ω	180mH	bus 6-7	45 Ω	56mH
bus 8	6.3kv	-	-	bus 13-4	54 Ω	63mH
bus 9	-	135 Ω	167mH	bus 12-4	43Ω	100mH
bus 10	-	58 Ω	127mH	bus 12-16	36Ω	113mH
bus 11	-	100Ω	100mH	bus 16-17	24 Ω	55mH
bus 12	-	10Ω	100mH	bus 17-10	36 Ω	85mH
bus 13	-	48Ω	100mH	bus 10-9	78 Ω	125mH
bus 14	-	67 Ω	97mH	bus 9-11	85 Ω	79mH
bus 15	6.3kv	-	-	bus 10-6	96 Ω	150mH
bus 16	-	33Ω	65mH	bus 6-9	110 Ω	138mH
bus 17	-	78 Ω	125mH	bus 6-28	108Ω	124mH
bus 18	-	10Ω	100mH	bus 15-14	89 Ω	119mH
bus 19	6.3kv	120Ω	150mH	bus 18-19	76Ω	106mH
bus 20	-	120Ω	168mH	bus 19-20	79 Ω	98mH
bus 21	-	125Ω	130mH	bus 20-10	86 Ω	110mH
bus 22	-	25Ω	90mH	bus 22-21	55Ω	103mH
bus 23	-	110 Ω	138mH	bus 21-10	40 Ω	75mH
bus 24	-	10Ω	100mH	bus 27-28	55Ω	69mH
bus 25	6.3kv	10Ω	100mH	bus 28-30	64Ω	78mH
bus 26	-	10Ω	100mH	bus 27-30	81 Ω	93mH
bus 27	-	10Ω	100mH	bus 15-18	112 Ω	97mH
bus 28	-	10Ω	100mH	bus 15-23	106Ω	136mH
bus 29	-	89Ω	189mH	bus 23-24	93Ω	131mH
bus 30	-	115Ω	198mH	bus 24-22	89 Ω	124mH
				bus 24-25	40 Ω	75mH
				bus 25-26	55Ω	69mH
				bus 28-27	64Ω	78mH
				bus 27-29	81 Ω	93mH
				bus 29-30	112 Ω	97mH

## REFERENCES

- [1] Akagi H. "New trends in active filters for power conditioning". *IEEE Trans Ind. Appl.*,1996; 32(6): 1312–22
- [2] A.Mansoor, W.M.Gardy, P. T. Staats, R. S. Thallam, M. T. Doyle, and M. J. Samotyj, "Predicting the net harmonic current produced by large numbers of distributed single phase computer loads." *IEEE Trans Power Delivery*, 2016;10:2001-2006.
- [3] S.Dhandayuthapani,C.Sharmeela, "Proportional Resonant controlled shunt active filter in IEEE nine bus system with improved dynamic performance"*International journal for Applied science and Engineering Tech (IJRASET)*,2018;6(1):1312-1320.
- [4] H. Rudnick, Juan Dixon and Luis Moran, "Active power filters as a solution to power quality problems in distribution networks,"*IEEE power & energy magazine*, 2003;32-40.
- [5] S.Dhandayuthapani,K.Anisha, "Proportional Resonant Controlled Shunt Active Filter in IEEE Thirty Bus System with Improved Dynamic Time Response".*International Journal of Engg.and Tech.*2018;7(4.19):334-339.
- [6] Purigilla Venkata Ramkumar, Munagala Surya Kalavathi "Fractional Order PID Controlled Interleaved Boost converter Fed Shunt Active Filter System"*International journal of power electronics and drives system(IJPEDS)* 2018; 9(1):126-138.
- [7] L. Saribulut, A. Teke, M. Tumay, "Artificial neural network based discrete fuzzy logic controlled active power filter", *IET Power Electronics*, 2014;7(6):1536-1546.
- [8] P.S. Puhan, P.K. Ray, G. Panda, "Development of Real Time Implementation of 5/5 rule based Fuzzy Logic Controller Shunt active Power Filterfor Power quality Improvement", *IJEEPS*,2016;17(6):607-617.
- [9] T.-L. Lee, Y.-C. Wang, J.-C. Li, J. M. Guerrero, "Hybrid active filter with variable conductance for harmonic resonance suppression in industrial power systems", *IEEE Trans. Ind. Electron.*, 2015;62(2):746-756.
- [10] J. He, Y. W. Li, F. Blaabjerg, X. Wang, "Active harmonic filtering using current-controlled grid-connected DG units with closed-loop power control", *IEEE Trans. Power Electron.*,2014;29(2):642-653.
- [11] Salem Rahmani, Abdelhamid Hamadi, Kamal Al-Haddad, Louis A. Dessaint, "A Combination of Shunt Hybrid



- Power Filter and Thyristor-Controlled Reactor for Power Quality", *IEEE Transactions On Industrial Electronics*,2014;61(5): 2152-2164.
- [12] A. Hamadi, S. Rahmani, K. Al-Haddad, "Digital control of a shunt hybrid power filter adopting a nonlinear control approach", *IEEE Trans. Ind. Inf.*,2013;9(4):2092-2104.
- [13] Hatem Zeineldin, Parag Kanjiya, Vinod Khadkikar, "Optimal control of Shunt Active Power Filter to meet IEEE Std. 519 Current Harmonic Constraints under Nonideal Supply Condition", *IEEE Trans. On Power Electronics*,2015;62(2):2015.
- [14] Anup Kumar Panda, Sushree Sangita Patnaik, "Analysis of cascaded multilevel inverter for active harmonic filtering in distribution network", *Electrical Power and Energy Systems*,2015;66:216-226.
- [15] L. Feng, Y. Wang, "Modeling and resonance control of modular three-level shunt active power filter", *IEEE Trans. Ind. Electron.*,2017;64(9):7478-7486.
- [16] J. C. Alfonso-Gil, E. Perez, C. Arino, H. Beltran, "Optimization algorithm for selective compensation in a shunt active power filter", *IEEE Trans. Ind. Electron.*, 2015;62(6):3351-3361.
- [17] Z. Shu, M. Liu, L. Zhao, S. Song, Q. Zhou, X. He, "Predictive harmonic control and its optimal digital implementation for MMC-based active power filter", *IEEE Trans. Ind. Electron.*,2016;63(8):5244-5254.
- [18] G. Carlos, C. B. Jacobina, E. Santos, "Shunt active power filter based on cascaded transformers coupled with three-phase bridge converters", *IEEE Trans. Ind. Appl.*,2017;53(5):4673-4681.
- [19] M. Salimi, J. Soltani, A. Zakipour, "Experimental design of the adaptive backstepping control technique for single-phase shunt active power filters", *IET Power Electron.*,2017;10(8):911-918.
- [20] G.Muni Reddy, T.Gowri Manohar, "Fuzzy logic controller for Grid connected wind energy conversion system", *Indonesian journal of Electrical Engineering and Informatics(IJEET)*, 2018;6(1):37-44.
- [21] Garim Sinha, Pankaj Kumar Goswami, Sudhir Kumar Sharma, "A comparative Strategy Using PI and Fuzzy Controller for Optimization of Power Quality Control", *Indonesian journal of Electrical Engineering and Informatics(IJEET)*, 2018;6(1):118-124.

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