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.

Keywords: PICSAF, FOPIDSAF, Thirty Bus System (TBS), Open Loop Thirty Bus System (OLTBS)

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

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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](image)

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

\[ FOPID(s) = K_p + \frac{K_i}{s} + K_d s^\mu \]  

(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 27th bus and the corresponding dynamic time-domain parameters are measured at that bus.

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.

![Closed loop TBS with PI controlled SAF](image)

**Figure 12. Closed loop TBS with PI controlled SAF**

![Voltage at bus-27 of PICSAF](image)

**Figure 13. Voltage at bus-27 of PICSAF**

![RMS voltage at bus-27 of PICSAF](image)

**Figure 14. RMS voltage at bus-27 of PICSAF**

![Current at bus-27 of PICSAF](image)

**Figure 15. Current at bus-27 of PICSAF**

![Real power at bus-27 of PICSAF](image)

**Figure 16. Real power 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.
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.

| 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 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.

| Controller                  | Current THD     |
|-----------------------------|-----------------|
| Open loop TBS               | 23.52%          |
| Closed loop PICSAF          | 4.96%           |
| Closed loop FOPIDCSAF       | 3.92%           |

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.

**Figure 22. Current at bus-27 of FOPIDCSAF**

**Figure 23. Real power at bus-27 of FOPIDCSAF**

**Figure 24. Reactive power at bus-27 of FOPIDCSAF**

**Figure 25. Current THD at bus-27 of FOPIDCSAF**
APPENDIX-I

LINE DATA AND LOAD DATA

| BUS NO | VOLTAGE | LOAD IMPEDANCE | BUS NO | LINE IMPEDANCE |
|--------|---------|----------------|--------|----------------|
|        |         | RESISTANCE     |        | RESISTANCE     |
|        |         | INDUCTANCE     |        | INDUCTANCE     |
| bus 1  | 6.3kv   | -              | bus 1-2| 1Ω             |
| bus 2  | -       | 10Ω            | bus 2-5| 3Ω             |
| bus 3  | 6.3kv   | -              | bus 5-7| 6Ω             |
| bus 4  | -       | 85Ω            | bus 3-1| 13Ω            |
| bus 5  | -       | 200Ω           | bus 4-2| 15Ω            |
| bus 6  | 6.3kv   | -              | bus 6-2| 23Ω            |
| bus 7  | -       | 125Ω           | bus 6-7| 45Ω            |
| bus 8  | 6.3kv   | -              | bus 13-4| 54Ω            |
| bus 9  | -       | 135Ω           | bus 12-4| 43Ω            |
| bus 10 | -       | 58Ω            | bus 12-16| 36Ω          |
| bus 11 | -       | 100Ω           | bus 16-7| 24Ω            |
| bus 12 | -       | 10Ω            | bus 17-10| 36Ω           |
| bus 13 | -       | 48Ω            | bus 10-9| 78Ω            |
| bus 14 | -       | 67Ω            | bus 9-11| 85Ω            |
| bus 15 | 6.3kv   | -              | bus 10-6| 96Ω            |
| bus 16 | -       | 33Ω            | bus 6-9| 110Ω           |
| bus 17 | -       | 78Ω            | bus 6-28| 108Ω          |
| bus 18 | -       | 10Ω            | bus 15-4| 89Ω            |
| bus 19 | 6.3kv   | -              | bus 18-9| 76Ω            |
| bus 20 | -       | 120Ω           | bus 19-20| 79Ω           |
| bus 21 | -       | 125Ω           | bus 20-10| 86Ω          |
| bus 22 | -       | 25Ω            | bus 22-21| 55Ω          |
| bus 23 | -       | 110Ω           | bus 21-20| 40Ω           |
| bus 24 | -       | 10Ω            | bus 27-28| 55Ω            |
| bus 25 | 6.3kv   | -              | bus 28-30| 64Ω            |
| bus 26 | -       | 10Ω            | bus 27-30| 81Ω            |
| bus 27 | -       | 10Ω            | bus 15-18| 112Ω          |
| bus 28 | -       | 10Ω            | bus 15-23| 106Ω          |
| bus 29 | -       | 89Ω            | bus 23-24| 93Ω            |
| bus 30 | -       | 115Ω           | bus 24-22| 89Ω            |
|        |         |                | bus 24-25| 40Ω            |
|        |         |                | bus 25-26| 55Ω            |
|        |         |                | bus 28-27| 64Ω            |
|        |         |                | bus 27-29| 81Ω            |
|        |         |                | bus 29-30| 112Ω           |

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