The Investigation of a Single-phase Shunt Hybrid Active Power Filter with FCS MPC and Hysteresis Control

by Asep Andang

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***Abstract*—It is assumed that the harmonics appeared in the electricity grid due to nonlinear loads significantly affect the quality of electric power. This harmonic can be reduced by using a power filter. In this paper, we will discuss the comparison of harmonic decreasing in a single-phase electrical system using the hysteresis method and Finite Control Set Model Predictive Control FCS-MPC. The filter used is a passive series filters connected with active shunt filters. The model simulation made was prepared using Simulink and testing was carried out using two different sets of parameters. From the test results, the Shunt hybrid active power filter decreased harmonics current controlled by hysteresis and FCS-MPC is very significant. Harmonic current before SHAPF installation is 23.92% on the grid, can be reduced by the hysteresis of 1.45%. For FCS-MPC, it is 0.43% and in the second test with the harmonic current before installing SHAPF is 45.59%. This can reduce the harmonic current by the hysteresis method to 1, 72% and for FCS MPC 0.94%. From the test, it can be found FCS MPC method is more effective in reducing current harmonics.**

***Keywords*— harmonics, hysteresis, finite control set-model predictive control.**

I. Introduction

Electric power quality is an essential parameter in power system. With the quality of electric power, we can know various things and conditions on the grid, load, and generation. The poor quality of electricity in the load will affect the grid and will eventually affect generation.

One of the parameters that are of the significantly affected quality of electric power is the emergence of harmonics due to nonlinear loads[1]. The nonlinear load will generate frequency due to the switching process of power electronics at load; this frequency will reduce the quality of electric power.

Reduction of harmonics on power systems has been done. When the harmonics have not significantly affected the electric power system, the reduction process is carried out using passive filters [2].

Passive filters succeed in reducing the level of a harmonic waveform at that time. However, when the load starts a complex and dynamics, the passive filter is no longer able to work optimally due to the rigid shape and is only able to reduce the amount of static order of specific order [3]. Another development of harmonic reduction after passive power filters is the use of active filters involving converters[4]. The power converter functions are to inject currents in systems which have harmonic waveforms without fundamental wave phases. Various active power filter topologies were developed with a combination of RLC passive components.

The latest development in harmonic reduction technology on a grid is a hybrid power filter[5][6]. The hybrid filter is a compound of passive filters and active filters. Many hybrid filter configurations have been developed by combining passive filters and active filters. Likewise, the variation filter component is carried out with a combination of RL and LC.

Control for hybrid filters has made significant progress. The initial development is done by relying on simple hardware functions, now control uses a complex system through the development of microprocessor technology. Some control models continue to develop such as hysteresis[7][8], SMC control[9][10], fuzzy[11][12], GIPT[13][14] and the last is MPC[15][16].

MPC Control Starts in use today due to the development of microcontroller technology began to support this control process[17]. This MPC began to be used in three-phase power filters with various filter topologies [18][19][20]. The use of MPC single-phase power filters also began to be used by using RL filters[21] then the use of SRF as a harmonics extractor [22].

In this paper, we will discuss the comparison between single-phase shunt hybrid active power filter based on hysteresis control and MPC control using PQ modified method for current reference generation in different load change conditions.

II. Single Phase Shunt Hybrid Active Filter

The proposed circuit can be seen in Fig. 1. The passive circuit consists of two passive filters that in series with the grid, and one is connected shunt with the grid.

A. Single Phase Shunt Hybrid Active Filter

The series passive filter was chosen because it can eliminate harmonics, but this filter has a large impedance that affects the system. The passive shunt filter combination functions to reduce harmonics that cannot be removed by series filters.

Passive filters are tuned to third-order harmonics with a passive dump filter type[23] which serves as one of them to correct the power factor. For the shunt filter, it is used single with the third, fifth seventh and eleventh order of the harmonic filter. This selection is made because the order is the most prominent in system harmonics.

For active filters using a voltage source single phase inverter with dc capacitor link control is done in two methods, namely the hysteresis method and FCS MPC. Inverter control the hysteresis method uses modulation to control the inverter's leg to produce the current we needed to reduce harmonics, while the control with the finite control set method predictive control FCS-MPC modulator is no longer needed to control the inverter and this is an advantage of MPC control[24], [25].

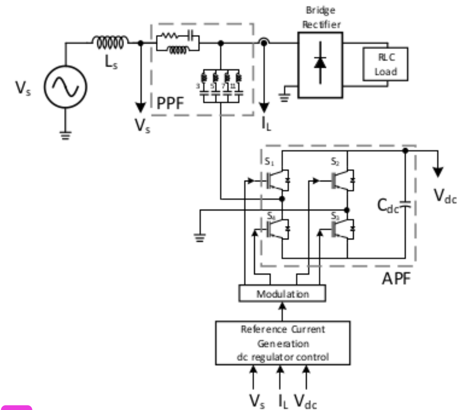


Fig. 1. Single-Phase shunt hybrid active power filter

B. Reference Current Generation

Akaqi [3] introduced Instantaneous Reactive Power Theory or IRPT, known as PQ method. This method describes the flow into two parts, namely p and q, but this Theory is developed in a three-phase system.

To control voltage source inverter both in hysteresis and FCS-MPC, we need to generate reference current by using the modified PQ method. This method is shown in Fig.2

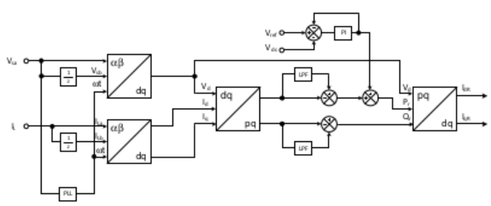


Fig. 2. Diagram block PQ modified

The diagram blocks the αβ transform into dq frame then the dq frame transforms into the pq frame. IPRT can be used in single-phase by transforming a magnitude of a single-phase into two-phase by shifting the original phase magnitude by 180º to $v_{s\alpha}$ and $v_{s\beta}$ using the equation (1)

$$\begin{bmatrix} v_{s\alpha}(\omega t) \\ v_{s\beta}(\omega t) \end{bmatrix} = \begin{bmatrix} v_s(\omega t) \\ v_s(\omega t + (\pi/2)) \end{bmatrix} = \begin{bmatrix} V_m \sin(\omega t) \\ V_m \cos(\omega t) \end{bmatrix} \quad (1)$$

Similarly, the current changes into $i_{s\alpha}$ and $i_{s\beta}$ according to equation (2)

$$\begin{bmatrix} i_{L\alpha}(\omega t) \\ i_{L\beta}(\omega t) \end{bmatrix} = \begin{bmatrix} i_L(\omega t + \varphi_L) \\ i_L(\omega t + \varphi_L + \pi/2) \end{bmatrix} \quad (2)$$

Then the magnitude that has changed in the αβ coordinate is converted to magnitude dq by using equation (3) to get v_d and v_q, but what is used in transformation pq only v_d which will be used in the conversion process to be the amount of pq[26].

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \end{bmatrix} = \begin{bmatrix} \sin \omega t & -\cos \omega t \\ \cos \omega t & \sin \omega t \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (3)$$

Then change from dq to pq by involving v_d, i_{Ld} and i_{Lq} to produce power p and q using equation (4)

$$\begin{bmatrix} p_g \\ q_g \end{bmatrix} = \frac{v_d}{2} \begin{bmatrix} i_d \\ -id_q \end{bmatrix} \quad (4)$$

The output of p is then filtered by LPF to define the harmonic current. After obtaining a harmonic value then it is converted into a reference current with the d-q coordinate that will be used as a reference in inverter modulation.

PI control used in the regulation of dc voltage Vdc to be stable according to the reference.

III. HYSTERESIS CURRENT CONTROL TECHNIQUES

The control technique using hysteresis is the most uncomplicated technique to implement and has a fast dynamic response. This hysteresis method consists of a hysteresis band which provides smooth transmission with a fixed frequency of switching. This method will produce compensation currents used for inverter switching [7].

From Fig. 3 it can be seen that the results of the generation of reference currents I_{dR} and I_{qR} compared with current load I_{load} then with the hysteresis method will produce a paired switching pattern but opposite between S_1 and S_2 then S_3 and S_4.

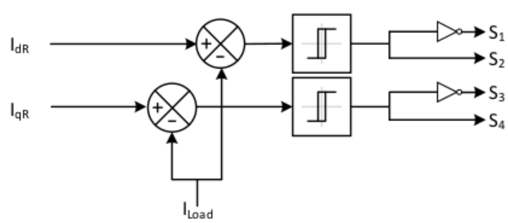


Fig. 3. Hysteresis method

IV. FINITE CONTROL SET MODEL PREDICTIVE CONTROL

The basic concept of the Predictive Control model is shown in Fig. 4, which describes the flow of the MPC system.

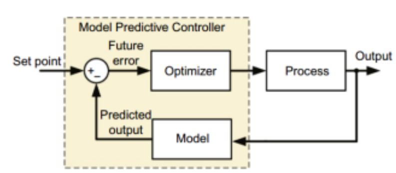


Fig. 4. FCS-MPC method

The Predictive Control Model predicts the following output by optimizing the reference model for the prediction models available based on the specified sample time. The process can be done by first modeling the circuit using the Kirchoff equation. After that, compare the prediction difference value with a reference current to find the smallest difference based on the switching function of VSI. Optimizing is done repeatedly based on the time function so that the switching pattern of the inverter can be obtained.

To find out the magnitude of the filter current, we get from the equivalent simplified circuit Fig. 5 in the form of equation (5)

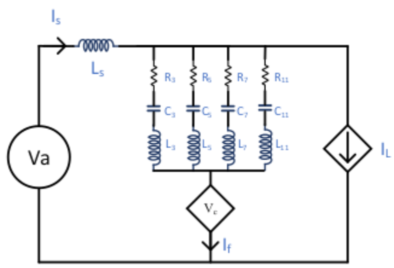


Fig. 5. The equivalent circuit shunt active power filter

$$V_a = -L_f \frac{di_f}{dt} - R_f . i_f - \frac{1}{C_f}\int i_f \, dt + V_c \qquad (5)$$

With V_a is the voltage on the hybrid filter and the V_c voltage on the inverter which is influenced by the S_1 to S_4 switching. Equation (5) is then converted into a discrete quantity so that it produces a predictive current

$$i^p_{f(k+1)} = \sum_3^n \left(\frac{1}{\frac{L_f}{T_s}+R_f+\frac{T_s}{C_f}} \left(-v_{c(k)} + \frac{L_f}{T_s}\right) i_{(k)} - \left(\frac{T_s}{C_f}\right) i_{(k)} \right) + sV_{dc} \qquad (6)$$

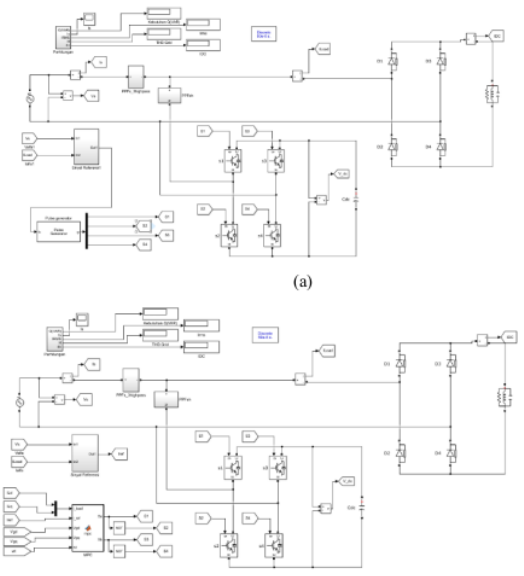
With n is harmonic order to be eliminate using passive power filter 3,5,7 and 11 Then this prediction current is compared with the reference current generated by using equation (7) as cost function, which is found to have the smallest difference and is formed into a load-based switching pattern.

$$g = \left| I_{ref_k} - I^p_{(k+1)} \right| \qquad (7)$$

V. Simulation and Results

Simulation of hysteresis and MPC models is done using Simulink, for a series of hysteresis models, as shown in Fig. 6a while for the MPC model series can be seen in Fig. 6b.

Testing with each model is done twice with different parameters to find out how much each model can reduce harmonics.



(a)

(b)

Fig. 6. Modeling Systems; a) Hysteresis modelling, and b) FCS-MPC modelling

A. First Test

This first test uses an uncontrolled rectifier load that is connected to the load RL parallel to C as shown in Fig. 7. RLC parameters can be found in Table I

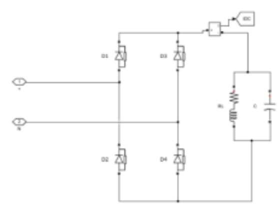


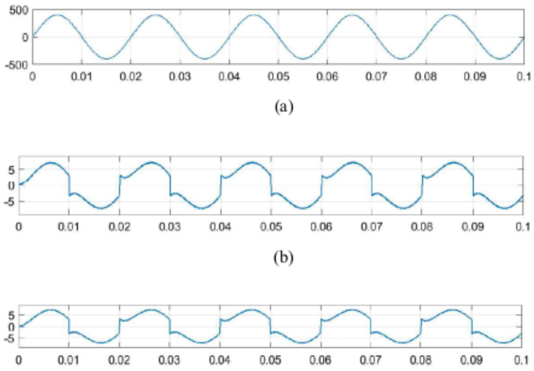
Fig. 7. Testing of nonlinear loads

In table I, we can see the magnitude of the RLC value used in the test

TABLE I. First Test Parameter

Components	Symbol	Value
Resistor	R	50 Ohm
Inductor	L	79.61 mH
Capacitor	C	1 µF

Initially, the non-filtered test produces a current waveform in the load equal to the source exposed by harmonics illustrated in Fig. 8



(a) (b) (c)

Fig. 8. Waveforms at source and load before filter installation; a) Voltage waveform in source, b) Current waveform in source, and c) Load current waveform

FFT analysis used to find out THD of harmonic current. From FFT as in Fig. 9, the analysis of THD was obtained at 23,92%

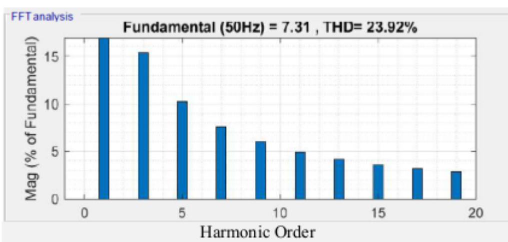
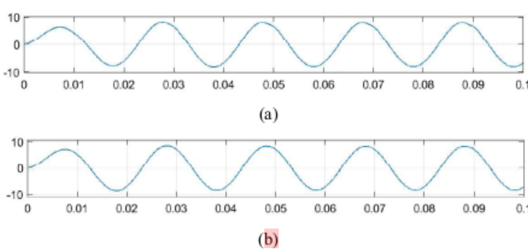


Fig. 9. Harmonic current spectrum without SHAPF

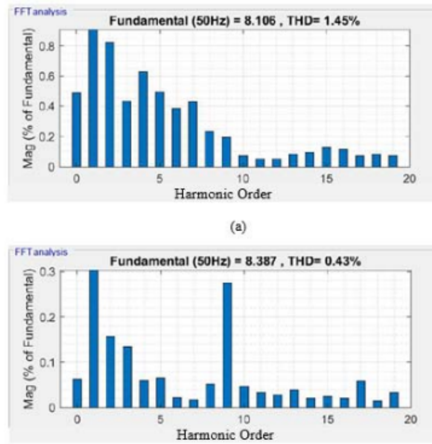
After installing the SHAPF using both the hysteresis method and the FCS-MPC method, current waveforms have improved in the power supply in each method, as in Fig.10



(a) (b)

Fig. 10. Harmonic Waveform after Installing the Power Filter; a) current waveform after shunt hybrid filter installed with hysteresis method, and b) current waveform after shunt hybrid filter installed with the FCS MPC method

Although the current waveforms in the picture above are pure sinusoidal if we analyze them using FFT, Fig.11 describes the THD differences between the two methods.



(a) (b)

Fig. 11. The comparison of THD spectrum after the filter is installed with each method; a) Harmonic spectrum of the hysteresis method, and b) The harmonic spectrum of the FCS MPC method

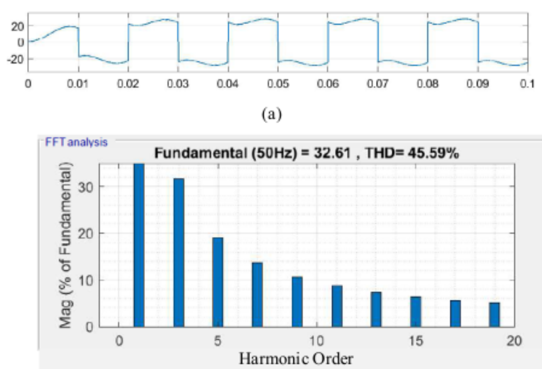
B. *The Second Test*

The second test is done to find out when the load varies in the parameter value to the extent to which the model made can reduce harmonics with different VARs. The second test has parameters shown in Table II.

TABLE II. SECOND TEST PARAMETER

Component	Symbol	Value
Resistor	R	10 Ohm
Inductor	L	79.61 mH
Capacitor	C	1 µF

The test results show that harmonics with loads as in table 2 have a THD of 45.59% as in Fig.12



(a) (b)

Fig. 12. wave and spectrum before Installation SHAPF; a) Source flow with the second test parameter, and b) Harmonic spectrum before filter installation

The hybrid filter is installed with both methods so that the form of the wave is obtained in Fig. 13

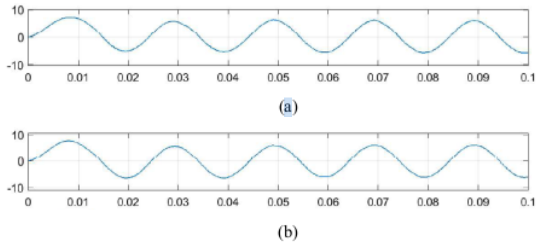


Fig. 13. comparison of load current waveforms with the hysteresis and FCS MPC methods; a) The source waveform after installing the hybrid filter with the hysteresis method, and b) Source waveforms after installing hybrid filters with the FCS MPC method

After being analyzed using the FFT method, THD was obtained for hysteresis of 1.72% while for FCS MPC it was 0.94% as in the Fig.14.

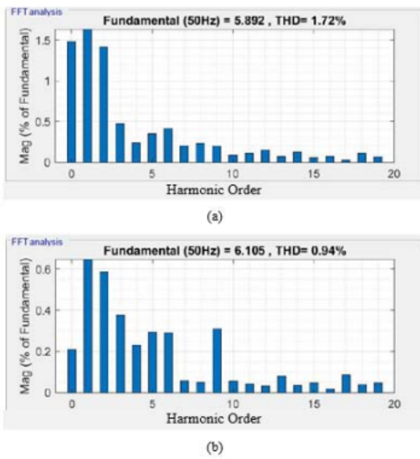


Fig. 14. comparison of the source flow spectrum with the hysteresis and FCS MPC methods; a) Harmonic spectrum of source current waves using the hysteresis method, and b) Harmonic spectrum of source current waves with the FCS MPC method

C. Testing with Linear Load

This test is conducted to see the model working in conditions when the load does not have significant harmonics by using R load with a rating of 0.6 kVA, the filter with the hysteresis method turns out to have a resonance with the load. Fig. 15 shown a resonance current waveform.

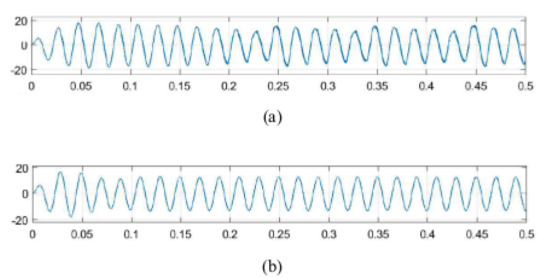


Fig. 15. comparison of waveforms when linear loads; a) Waveform testing for linear loads using the Hysteresis method, and b) Waveform testing for linear loads with the FCS MPC method

From Fig.15, the hysteresis method with R turns out to cause instability in the system; this is shown by the amplitude of the load current that keeps changing, meanwhile when the FCS-MPC method is used, the load current amplitude is more stable.

VI. CONCLUSION

From the simulation results obtained for hybrid shunt active filter with the hysteresis, the method produces harmonic reduction until the final THD becomes 1.45% and 1.72% while for Hybrid shunt active filter with FCS MPC method the harmonic reduction results so that the THD becomes 0.43% and 0.94%. In testing with linear load, a hybrid shunt active filter with hysteresis results in changes in the current amplitude of the system while the use of a single-phase SHAPF with FCS MPC method does not result in changes in the current amplitude of the system.

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