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Self-adaptability parallel active filter to load variations study

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ABSTRACT

Due to the increasing use of power electronics equipment, the quality of energy in the electrical network is deteriorating sharply. Indeed, this equipment consumes non-sinusoidal currents, even if they are powered by a sinusoidal voltage, and behaves like generators of harmonic currents. To "clean up" the network, there are several means, among them; the parallel active filter (PAF) which is the most used means because it has proven its effectiveness for the elimination of harmonics caused by a non-linear load. However, this PAF must prove its effectiveness constantly, because the unexpected variation of the loads supplied by the electrical network can call into question its effectiveness. The main objective of this work is to confirming that PAF is a permanent filter and adapts automatically and instantaneously to any load. For this, several simulation tests were carried out under MATLAB/Simulink. The results obtained are very satisfactory, as they confirmed the robustness and self-adaptability of the filter with respect to the sudden variation in loads, the tests carried out on the PAF also show us that the response of the filter is done almost in real time.

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1. INTRODUCTION

The use of power electronics and information technology or IT equipment, whether by consumers of electrical energy or by producers, hardly becomes an optional choice, but it is an obligation, because: On the consumer side, and by way of example, the use of equipment such as rectifiers, dimmers, cycloconverters in electrical energy conversion installations is a necessity given their considerable contribution to improving performance, and efficiency of these systems. On the producer side, and also by way of example, the need to integrate other energy sources (wind and photovoltaic), and to adapt them with the parameters of the existing electrical network requires the use of power electronics.

However, the increasing use of this equipment and others (the tool of computing and communication) contributes to the degradation of the quality of energy in the electrical network. They participated in deteriorating the “quality” of the current and voltage of the distribution networks. In fact, these systems consume non-sinusoidal currents, even if they are supplied by a sinusoidal voltage, and behave as generators of harmonic currents, and through the short-circuit impedance of the network, the circulation of these disturbed currents will also cause harmonics and voltage imbalances, which will be superimposed on the nominal voltage of the electrical network and cause "harmonic pollution" which remains one of the major problems which degrades the quality of electrical energy in distribution systems [1]–[3]. The effects of harmonics are numerous, the most known are: i) The increase in losses by Joule effect; ii) Degradation of the power factor of the installation; iii) Devices malfunction; iv) Destruction of capacitors or circuit breakers under the effect of strong harmonic currents amplified by resonance phenomena; and v) Overheating of transformers and neutral conductors, and the long-term effects which translate into accelerated fatigue of the equipment.

To avoid all these consequences, active filtering is the most used means because it has proven its effectiveness. The efficiency index of the active filter is represented by a decrease in the harmonic distortion rate (THD). As much as the THD value is low, the filtering is better.

Many researchers have worked on the parallel active filter (PAF), and have proven its effectiveness in reducing and even canceling the harmonics and interharmonics caused by a nonlinear load, but they generally limit themselves to a single test for a nonlinear load. While in everyday life the loads supplied by the electrical network have never been fixed, on the other hand, we often find that the loads (whether linear or non-linear) are very variable, which forces us to see if our PAF always remains reliable and efficient if the loads vary, hence a test of robustness and self-adaptability is necessary [4]–[6].

The robustness and self-adaptability of the PAF translate into the instantaneous reaction, or within an acceptable time interval, of the filter and filtering results after each load change. Preview study [2] we used a PAF with which we were able to reduce the THD of the interharmonic current created by a polluting load to very acceptable values. In this present work, we continue our contribution by carrying out tests on the filter used to examine its robustness and its self-adaptability to the variation of the load.

2. PRINCIPLE OF FUNCTIONING OF PARALLEL ACTIVE FILTER (PAF)

The parallel active filter (PAF) consists of a voltage inverter controlled by the pulse width modulation (PWM) technique, connected in parallel with the polluted load, as shown in Figure 1. The inter-harmonic currents are calculated through an identification algorithm using PWM to form the control of the PAF [7]–[9]. The direct current bus voltage (DCBV) is regulated by a classic proportional-integral (PI) [10], [11]. The PAF produces inter-harmonic currents which will be injected into the electrical network of the same amplitude but in phase opposition with the inter-harmonic currents caused by the load; which will eliminate them and obtain the return as a linear current. The speed of control of the PAF improves the quality of the power supply of the network in real time to limit the likely damage [12]–[15]. Figure 1 represents the principal function of the PAF.

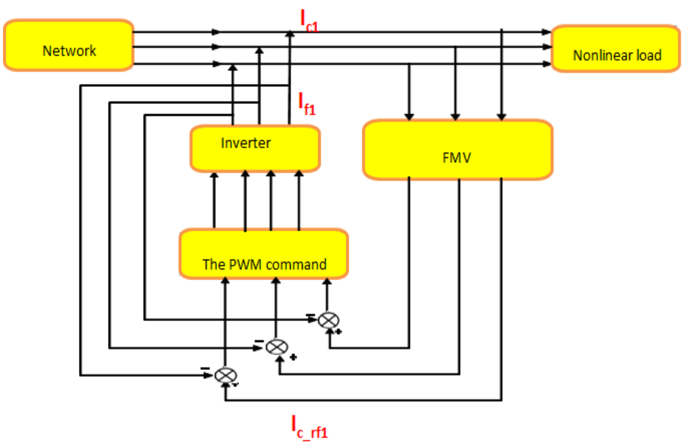


Figure 1. Principle of functioning diagram of the parallel active filter (PAF) [2]

The PAF separates the fundamental component of the load current (f= 50 Hz) from the harmonic and inter-harmonic components (f ≠ 50 Hz) [16]–[20]. The mathematical model of the multi-variable filter (MVF) is developed and the relationship between the quantities of inputs and outputs having an integral effect as indicated by (1) [21]–[25].

$$\int i_{\alpha\beta}(s) = e^{j\omega_c t} \int e^{-j\omega_c t} . i_{\alpha\beta}(t) dt \quad (1)$$

In this present work, we have chosen the so-called "Global MVF" [2], method shown in Figure 2.

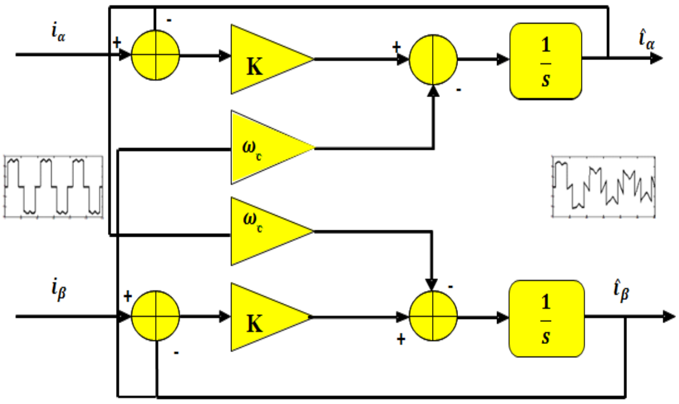


Figure 2. FMV circuit diagram [2]

In Laplace form in (1) will be (2).

$$H(s) = \frac{\hat{\imath}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = \frac{s+jw_c}{s^2+w_c^2} \tag{2}$$

We add two constants k_1 and k_2 as in (3).

$$H(s) = \frac{\hat{\imath}_{\alpha\beta}(s)}{i_{\alpha\beta}(s)} = K_2 \frac{(s+K_1)+jw_c}{(s+K_1)^2+w_c^2} \tag{3}$$

With:
w_c: The cut-off pulse of the filter;
K_i: positive constants;
$i_{\alpha\beta}$: The input currents of the FMV;
$\hat{\imath}_{\alpha\beta}$: The output currents of the FMV;
For H (s) = 0 dB, it is necessary that: $K_1 = K_2 = K$.
Then, as in (4) and (5).

$$\hat{\imath}_\alpha = \frac{k}{s}[i_\alpha(s) - \hat{\imath}_\alpha(s)] - \frac{\omega_c}{s}.\hat{\imath}_\beta(s)) \tag{4}$$

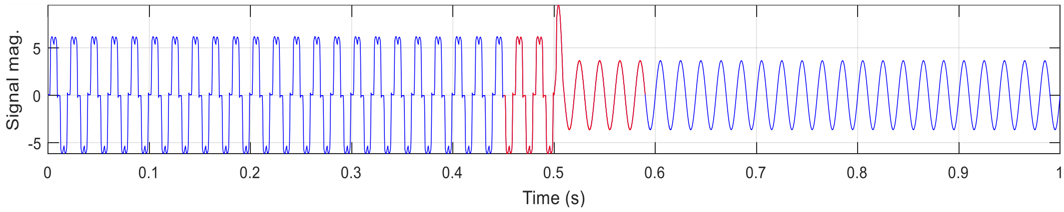
$$\hat{\imath}_\beta = \frac{k}{s}[i_\beta(s) - \hat{\imath}_\beta(s)] - \frac{\omega_c}{s}.\hat{\imath}_\alpha(s)) \tag{5}$$

3. TESTS RESULTS

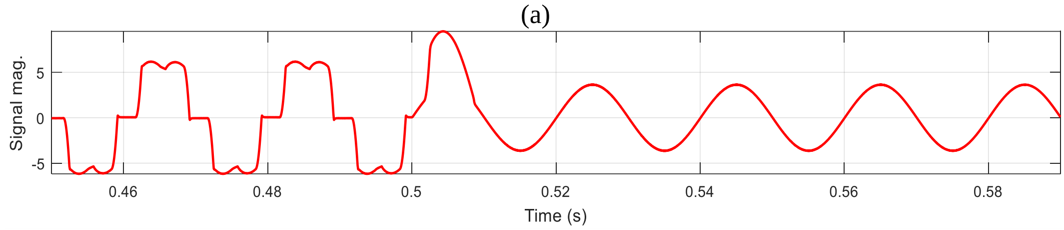
To test the robustness and self-adaptability of the PAF, we performed several tests in which we abruptly changed the load. The sudden modification of the load is made intermittently between a linear load and a non-linear load. After each load change, we observe the reaction of the parallel active filter. The details of the tests carried out are explained in the following parts:

3.1. First test

For the first test we started (at t=0) with a non-linear load (rectifier and resistor + inductor RL). But at time t=0.5 s, we replaced it with a linear load (three star-coupled resistors). The simulation results are shown in the following figures. Figure 3(a) is in full representation and Figure 3(b) in zoom show us that the transition from nonlinear load to linear load takes place in 0.01s and the nonlinear load comes into operation exactly at time 0.51 s. Figure 4(a) is in full representation and Figure 4(b) in zoom shows us that the PAF reacts at exactly the same time that the nonlinear load is introduced (exactly at time 0.51 s). This observation is well and truly confirmed by the current of the filter represented by Figure 5(a), which is in full representation, and Figure 5(b) in zoom. The spike in DC bus voltage (Vdc) observed in Figure 6 is due to the state transition of the inverter and lasted only a few milliseconds.

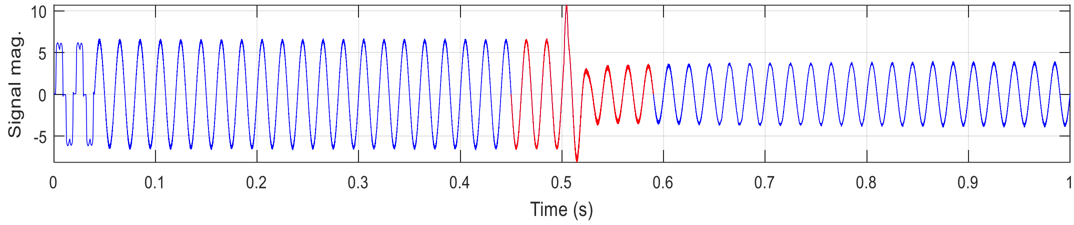


(a)

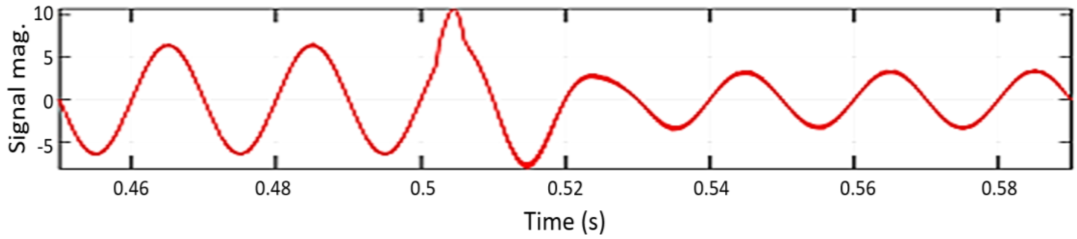


(b)

Figure 3. Load current: (a) full representation of load current and (b) representation in zoom of load current

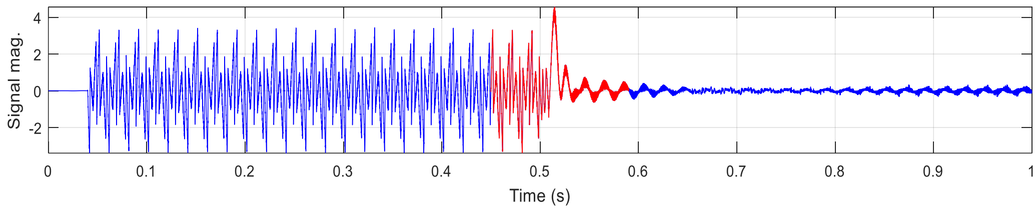


(a)

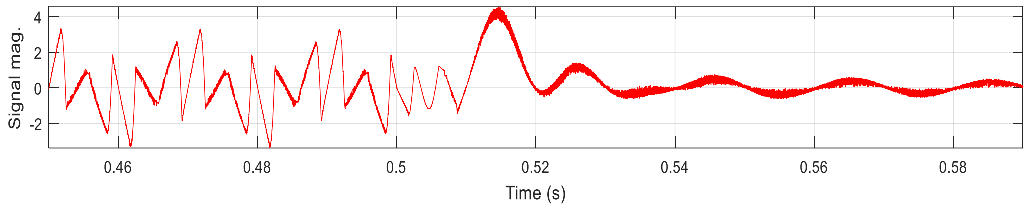


(b)

Figure 4. Network current: (a) full representation of network current and (b) representation in zoom of the network current



(a)



(b)

Figure 5. Filter current: (a) full representation of filter current and (b) representation in zoom of filter current

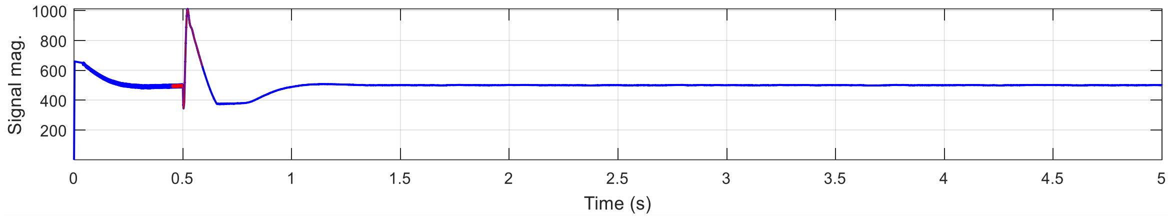


Figure 6. The Vdc voltage

3.2. Second test

In this second test, the order of load variation was changed (linear load then non-linear load). We started (at t = 0) with linear load (three star-coupled resistors). Then at time t = 0.5 s we replaced it with a non-linear load (rectifier and resistor + inductor RL). The simulation results are shown (as a zoom) in the following figures. By changing, in the 2nd test, the order of change of the loads compared to the 1st test, as shown in Figures 7-9 confirms the observations made in the 1st test. The reverse peak of the DC bus voltage observed in Figure 10 is due to the state transition of the inverter, it is an instantaneous peak.

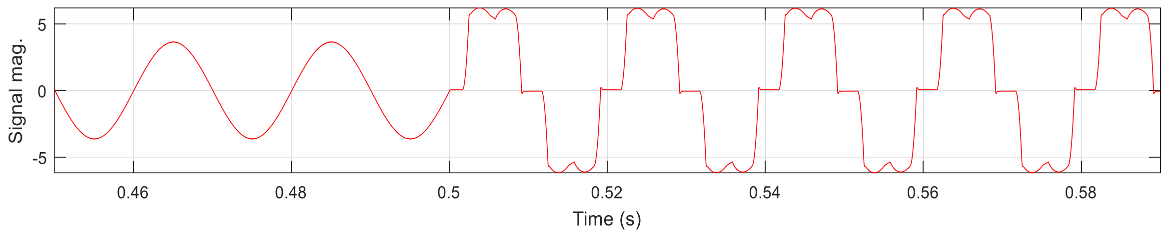


Figure 7. Load current

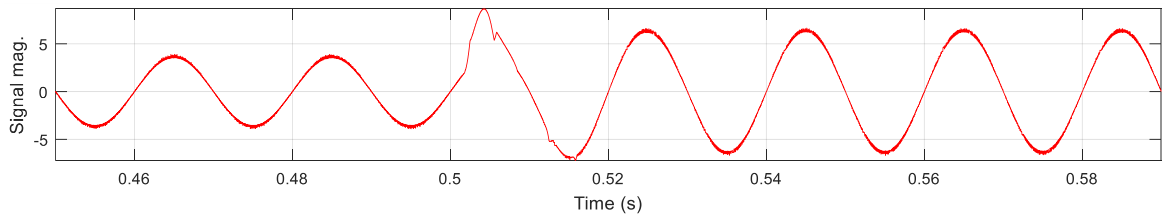


Figure 8. Network current

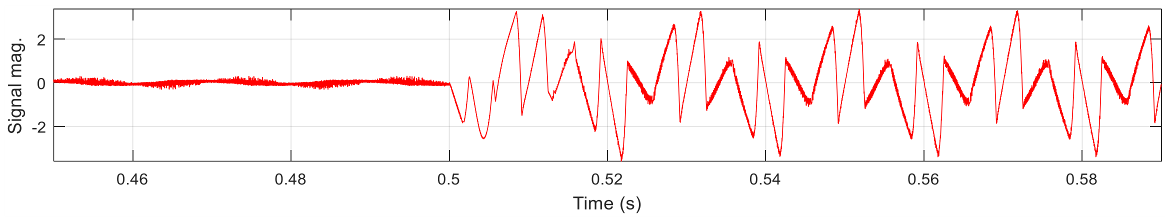


Figure 9. Filter current

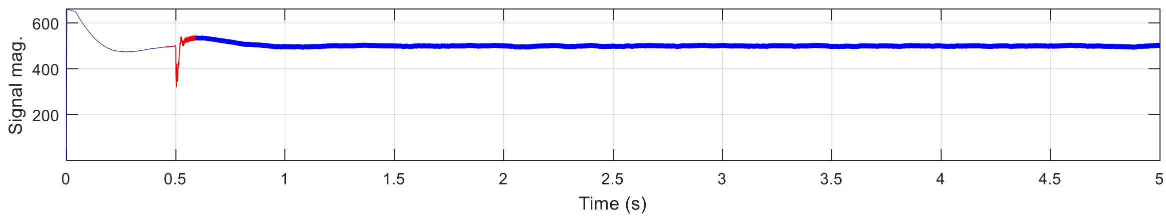


Figure 10. The Vdc voltage

3.3. Third test

Finally, we proceeded in a third test to two sudden load changes: at t = 0 s, we put a linear load, then at t = 0.3 s we replaced it by a non-linear load, finally at t = 0.5 s we changed to a linear load. The simulation results are shown (as a zoom) in the following figures: Figure 11 represents the load current. By observing the network current curve as in Figure 12, and the filter current curve as in Figure 13, it is clearly seen that, despite having made three very rapid changes, the PAF reacts in real-time (at same time of the change) and eliminates almost all the harmonics by making the network current sinusoidal. The voltage peaks of the DC bus of the inverter observed in Figure 14 are short peaks and have no influence on the proper functioning of the PAF.

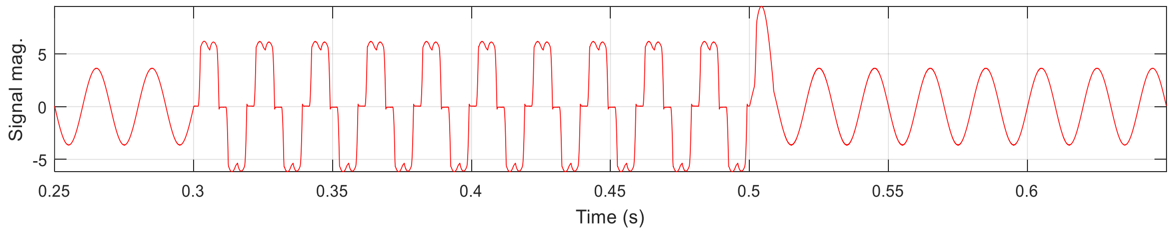


Figure 11. Load current

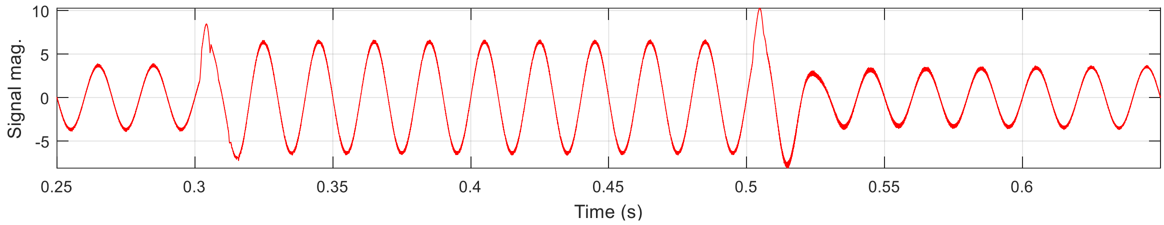


Figure 12. Network current

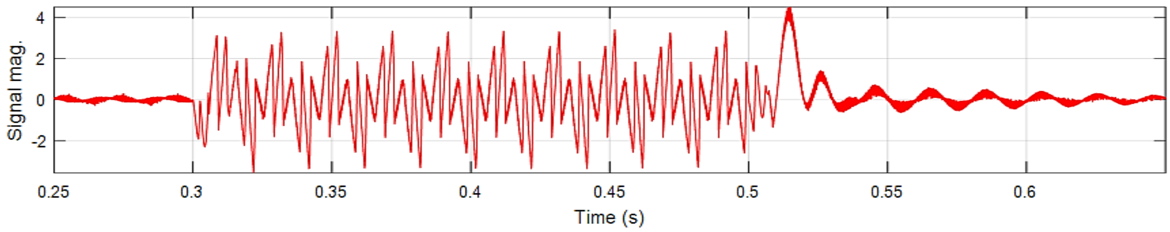


Figure 13. Filter current

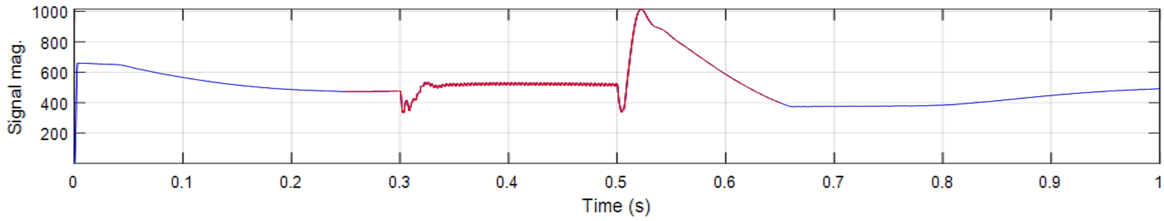


Figure 14. The Vdc voltage

4. CONCLUSION

With a general aim; this present work constitutes, a contribution to improving the quality of electrical energy in the distribution network, by eliminating harmonics and interharmonics caused by non-linear loads by a parallel active filter associated with the filter technique multivariable. However, more precisely, this work was about confirming that our parallel active filter can operate continuously regardless of the load and that it can react quickly and in real-time to any change in load. For this reason, we carried out several tests by simulation in MATLAB/Simulink. The results obtained allow us to draw the following remarks: i) The reaction of the filter to the transition from a non-linear load to a linear load takes place in 0.01 s. (1st test); ii) The same rapid reaction is observed during the transition from a linear load to a nonlinear load. (2nd test); iii) Despite having made three very rapid changes (3rd test), the parallel active filter reacts in real time (at the same time as the loads change) and eliminates almost all harmonics by making the network current sinusoidal; iv) In all three tests, the network current returns to its sinusoidal form after filtering; and v) The voltage (DC bus of the inverter) restores, in the three tests, its quasi-continuous form and within a very acceptable duration (a few milliseconds). These findings allow us to confirm that our filter is indeed robust and self-adapting with respect to different load variations.

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