Performance Evaluation of Adaptive Tabu Search Algorithm Optimized Sinusoidal Fryze Voltage Control based Hybrid Series Active Power Filter

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Abstract: A novel hybrid series active power filter to eliminate harmonics and compensate reactive power is presented and analyzed. The proposed active compensation technique is based in a hybrid series active filter using adaptive tabu search algorithm in the conventional Sinusoidal Fryze voltage control technique. The paper analyzes the proposed hybrid series active power filter when connected with load of 3-phase diode bridge rectifier with R-L branch directly. This paper intends to show the improvement between the performance of conventional scheme and ATS-optimized scheme. Simulation results obtained using MATLAB/Simulink confirm the viability of the proposed compensation technique.

Keywords: Harmonics, Series active filter, Passive filter, Hybrid power filter, Sinusoidal Fryze voltage control, Adaptive Tabu search algorithm.

1. Introduction

The compensation techniques applied in active and passive filters to eliminate current harmonics, voltage harmonics and to compensate reactive power have already been presented and published in the technical literature [1, 2, 3]. Shunt, series and hybrid active filter topologies have been conferred and demonstrated to be a feasible alternative for industrial compensation [5], [7]. Even though passive filters LC are most frequently used to compensate current harmonics, it is well recognized that they are not the most excellent solution, since they generate resonance problems, affect voltage regulation, and bring into being high inrush currents. Shunt active filter is a improved option for current harmonic and reactive power compensation; however its application in high power load compensation is still limited due to power semiconductors restrictions [2].

The series active power filter exertions as a voltage controlled source whereas the shunt active approach acts as a current controlled source. The series approach compensates for voltage distortion, unbalances, and regulation (sags and swells) [4]. Other well known topology is the hybrid filter [1], [7], [9], which uses a combination of active and passive filters, and is a good and successful alternative for current harmonics compensation. Now days, advance soft computing techniques are used widely in automatic control system or for optimization of the system applied. A few of them are such as adaptive tabu search [10]-[14], optimization of active power filter using Genetic algorithm[15]-[18], power loss minimization using particle swarm optimization[19], neural network control [20]-[24] applied in both machinery and filter devices.

This paper presents a dynamic compensation scheme that has been optimized using Adaptive tabu search algorithm enforced with a hybrid series active power filter, and is intended to compensate line current harmonics and reactive power generated by static converters.

The paper has been organized in the following manner. The APF configuration and the load under deliberation are discussed in Section II. The control algorithm for APF is discussed in Section III. Optimization using adaptive tabu search has been presented in Section IV. Comparative evaluation using MATLAB/Simulink results are discussed in Section V and finally Section VI concludes the paper.

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2. System Description

As shown in Figure 1, Hybrid Series Power filter improves the power quality and compensates the harmonics within the system. The series active filter ideally behaves as a controlled voltage source in such a way that the load voltage will have solely positive-sequence at the fundamental frequency component.

![Figure 1. Hybrid Series Active Power filter](image)

The voltages on the sources are given by $V_{sa}$, $V_{sb}$, and $V_{sc}$. Conversely, the relation among the supply voltage, the load voltage, and also the active filter voltage is given by

$$
\begin{bmatrix}
V_{sa} \\
V_{sb} \\
V_{sc}
\end{bmatrix} =
\begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix} -
\begin{bmatrix}
V_{ca} \\
V_{cb} \\
V_{cc}
\end{bmatrix}
$$

The fundamental series active filter voltages are synthesized by three single-phase converters with a standard dc capacitor. The reference voltage for these converters is calculated by the “PWM Control circuit block that has active filter controller” shown in figure 1.

We know that thyristor rectifier shown behaves sort of a current source; the voltage source may be split into its fundamental voltage source and harmonic voltage source. The series active filter behaves just like the controlled voltage source $V_c$ and also the shunt passive filter may be represented by equivalent impedance $z_F$. As per the fundamental compensation principle, the series active filter ought to synthesize the active impedance presenting zero impedance at the fundamental frequency and a high resistance $k$ at the source or load harmonic frequencies.

The harmonic current running in the source is dependent on both the load harmonic current $I_{lh}$ and the source harmonic voltage $\hat{V}_{Sh}$. $z_s$ presents the source impedance of the system.

It is given by

$$
i_{sh} = \frac{z_F}{z_F + z_s + k} I_{lh} + \frac{V_{sh}}{z_F + z_s + k}
$$

Where

$$
i_{sh} \approx 0 \quad \text{if} \quad k \gg z_s z_F
$$

The output voltage of the series active filter is given by;
\[ V_c = k \frac{z_F I_{Lh} + V_{sh}}{z_F + Z_S + k} \] (4)

\[ V_c \cong z_F I_{Lh} + V_{sh} \quad \text{if } k \gg z_S z_F \] (5)

Equation (5) shows beyond any doubt that the voltage rating of the series active filter \( V_c \) is
given by two factors; the primary term within the right hand side of the equation, which is
reciprocally proportional to the shunt passive filter’s quality factors, and also the second term
are equal to the source harmonic voltage.

The harmonic voltage on the shunt passive filter is given by

\[ V_{FH} = \frac{Z_S + k}{z_F + Z_S + k} z_F I_{Lh} + \frac{z_F}{z_F + Z_S + k} V_{sh} \] (6)

\[ V_{FH} \cong -z_F I_{Lh} \quad \text{if } k \gg z_S z_F \] (7)

The above equations show that by choosing \( k \gg z_S, z_F \), no source harmonic voltage shows
the shunt passive filter. Two harmonic current flows should be examined: one from the load to
the source and the other from the source to the load.

3. **Control Theory**

The series active filter controller produces the reference voltage that will be synthesized by
the PWM converter and positioned in series with the supply voltage, to force the load voltage,
to become sinusoidal and balanced.

Based on Sinusoidal Fryze Voltages Control Strategy, the series active filter controller is
composed by a circuit that senses the fundamental positive sequence component of the system
voltage and generate compensating voltage references by performing the distinction between
that fundamental component and the measured system voltages.

The blend of a shunt passive filter and a low-rated series active resulted in a very realistic
and economical way to filter harmonic currents. The concept adopted in this approach differs
from conventional shunt active filters or pure series active filters in terms of guaranteeing
better filtering characteristics as well as lower initial costs. The required rating of the series
active filter is mainly decided by the quality existing in the power system.

Though the quality factor of the shunt passive filter used in the experiments was equal to
14, it may be in the range of 50 to 80 in real cases. Therefore, the rated power of the series
active filter may be as small as 1% of the rated power of the nonlinear load (thyristor rectifier
or cycloconverter) if no background harmonic voltage lives in the source. This shows the way
to the significant conclusion that this combined series active filter and shunt passive filter is
one of the most suitable answers to high-power thyristor rectifiers, like those used in high–
voltage dc transmission system (HVDC) or cycloconverters.

In this approach, the active filter is attached in series with the passive filter, as shown in
figure 1. The composed branch of passive and active filters is connected in parallel, as closed as
achievable to the harmonic-producing load. This new method provides hybrid filters which are
somewhat different in circuit configuration; they are almost the same in operating principle and
filtering performance. Such a mixture with the passive filter makes it possible to significantly
reduce the rating of the active filter. Two passive filter tuned to compensate 5th & 7th harmonics
have been connected in parallel to series filter.

The function of the active filter is not to compensate for harmonic currents produced by the
thyristor rectifier, but to achieve harmonic seclusion between the supply and the load. As a
result, no harmonic resonance occurs, and harmonic current flows in the supply.
In this paper, Adaptive Tabu Search algorithm has been applied to find out the optimum value of PI controller parameters used in Sinusoidal Fryze Voltage control strategy and make the system optimum.

4. Optimization Using Adaptive Tabu Search Algorithm

Adaptive Tabu Search (ATS) is a modified version of original tabu search formula for combinational optimization problem suggested by Glover. This technique is very useful for solving non-linear continuous optimization problems. The modification which has been added into the new version is discredited continuous search space, back-tracking and adaptive radius.

In this paper, the proposed ATS method searches the optimum value of the proportional integral controller parameters i.e. \( K_p \) and \( K_i \) and the objective function is decided such as to give their optimum value with the conditions of minimum overshoot, rise time and settling time. Boundary of \( K_p \) and \( K_i \), their upper limits and lower limits, then radius value, conditions for ATS back tracking, objective function and stop criteria has been defined. Maximum Searching iteration (500 rounds) for ATS has been set as stop criterion. Figure 2 shows the flow chart for search of parameters using adaptive tabu search method.

Since this paper is predicated on the critical analysis based on THD of the source it has been seen that the objective function taken has shown its effectiveness, which may be seen from the reduction of THD.

Computational time has conjointly been seen terribly less i.e. within seconds, all iterations are over and optimum values of \( K_p \) and \( K_i \) is seen on MATLAB/Simulink compiler. We are able to see that this method is extremely stable, since it has been calculated offline so is accustomed replace the prevailing values. Strength of this algorithm can be understood by the nice results and less computational time. Convergence analysis has been done offline. Range of iterations with variation in \( K_p \) and \( K_i \) values has been taken to prove the pliability of the algorithm. This algorithm is extremely convenient to use due to the programming and fewer computational time. The practicability and advantage of the algorithm are verified by the simulation results. It is in no time. The parameters i.e. \( K_p \) and \( K_i \) has been set indiscriminately ab initio so it has been tuned by using this algorithm offline.

There has been a counter used, that will count the number of iterations and the program will stop automatically when count is equal to 500 i.e. stopping criteria is 500 iterations.

Objective function (O.F.) is defined by

\[
O.F.(T_{\text{Rise}}, T_{\text{Settling}}, P.O.) = A(T_{\text{Rise}}) + B(T_{\text{Settling}}) + C(P.O.)
\]  \hspace{1cm} (8)

\[
A + B + C = 1
\]  \hspace{1cm} (9)

P.O. is the percent overshoot.

\( T_{\text{Rise}} \) is the rise time.

\( T_{\text{Settling}} \) is the setting time.

A, B and C are the priority coefficients of \( T_{\text{Rise}}, T_{\text{Settling}}, P.O. \) respectively.

In this paper, the values of (A, B, and C are set to 0.33, 0.33, and 0.34, respectively. The ATS search can try and notice the most effective controller parameters to attain the minimum O.F. value.

Step 1: Tabu list and neighborhood list having values of \( K_p \) and \( K_i \) are loaded and counter has been set zero, which is able to check the number of iterations.

Step 2: Value of the objective function has been calculated for initial values of \( K_p \) and \( K_i \).

Step 3: Resultant of step 2 has been compared from the Tabu list and if it is better than it’s been compared from neighborhood list. If it’s not better than Tabu list solutions, then these values are modified by varying the values of \( K_p \) and \( K_i \).

Step 4: If the results don’t seem to be better than neighborhood list solutions, it will be saved in tabu list and so counter will automatically increased and there’ll be variation in \( K_p \) and \( K_i \) value and these value will replace the previous value and again go to step 3.
Step 5: If the results are better than neighborhood list solutions, it’ll be saved as best solution. 
Step 6: If variety of iteration i.e. count value is 500, the results with the optimum value of \( K_p \) and \( K_i \) will be shown otherwise it’ll check the counter value and vary the \( K_p \) and \( K_i \) values and go to step 3.

It has been seen that the objective function actually based on percent overshoot, rise time and settling time, however the THD results outcome are excellent and since, since this paper will the assessment of the system based on THD of source, detail equations and values for percent overshoot, rise time and settling time haven’t been given, only THD details have been mentioned.

Figure 2. Flow chart for search of parameters using ATS
5. Comparative Evaluation Using Simulation Results

The proposed scheme of Hybrid-Series Power filter (HPF) is simulated in MATLAB environment to estimate its performance. The load consists of a three-Phase diode bridge rectifier with R-L branch directly. The proposed control scheme has been simulated to calculate the performance of HPF and analysis through THD of source voltage and current. The simulation results clearly demonstrate that the scheme is able to successfully trim down the significant amount of THD in source voltage and current within limits of IEEE 519-1992. Simulation results have been analyzed on the basis of THD obtained. Simulation has been done for 15 cycles. Comparative evaluation of simulation using optimized SFV by ATS algorithm for series and hybrid power filter have been done.

A. Uncompensated system

After doing simulation in MATLAB/Simulink without using any filter (Figure 3) i.e. for Uncompensated System, it has been observed that the THD of source voltage found when load is connected with the system is 27.77%. By observing these data, we can easily understand supply has been polluted when load has been connected.

B. Performance of Series APF

During the analysis of simulation results based on THD, this has been observed (Figure 3) that while doing simulation of Series power filter based on Sinusoidal Fryze Voltages Control Strategy that the THD of source Voltage were 2.34%; whereas when model has been optimized using ATS algorithm has been used, it has been observed that the THD of source voltage reduces to 1.63% which is absolutely the improvement from conventional one. But it has been observed that THD for source current was more than specified limit in IEEE 519-1992 standard.

C. Performance of Hybrid APF

During the analysis of simulation results based on THD, this has been observed (Figure 4) that while doing simulation of Hybrid Series power filter optimized using ATS-SFV control has been used, it has been observed that the THD of source voltage reduces to 0.017% and THD of source current reduces to 0.013%; which is absolutely the improvement from both the series filter results. It has also been observed that THD for source current was within the specified limit of IEEE 519-1992 standard. The only problem which has been observed that some unbalancing between the phases was there, which can be removed using a parallel RC branch of appropriate value. Table I presents the statistical view of THD response for different filter and schemes.

<table>
<thead>
<tr>
<th>Strategy Applied</th>
<th>THD-V (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sinusoidal Fryze Voltage control (SFV) for series filter</td>
<td>2.34</td>
</tr>
<tr>
<td>ATS- SFV control for series filter</td>
<td>1.63</td>
</tr>
<tr>
<td>ATS- SFV control for Hybrid filter</td>
<td>0.017</td>
</tr>
</tbody>
</table>
Figure 3. Source voltage waveforms of uncompensated system, using series filter utilizing Sin Fryze voltage technique and using series filter utilizing ATS- Sin Fryze voltage technique

Figure 4. Waveforms of Source Voltage and source current for Hybrid power filter
Figure 5 presents the comparative bar chart for THD-V for different control schemes. We can see that hybrid power filter is the best as comparison to other schemes.

6. **Conclusion**

A novel ATS-Sin Fryze control technique for hybrid series power filter has been reported which clearly demonstrates its compensation ability. This also has been observed that adaptive tabu search algorithm has well optimized the model and increased the ability of conventional Sinusoidal Fryze Control model. From the simulation results of THD response, this can be easily seen that the proposed novel hybrid active filter is effective better than the series filter.

7. **References**


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