Kalman Filter based Neural Network Control Strategy with PI Controller for Optimum Performance of Series Active Power Filter

Praseeja P¹, Abdul Vahab P A²

¹MTech Student, Al-Ameen Engineering College, Kulappully, Kerala, India – 679 122
²Assistant Professor, Al-Ameen Engineering College, Kulappully, Kerala, India – 679 122

Abstract: Harmonics and reactive power have been a keydisquiet in power systems owing to the copious usage of power electronic converters during varied levels of its working. This increase will suppress the quality of the power of the system and there will be contamination in the power system leading to lesser efficiency and throughput. An active power filter when connected in series to the power system will help out in diminishing the harmonics within the system and appeasing the matter of reactive power throughout. Here, in the paper a neural network controller which is based on Kalman filter is connected to the active power filter to reduce the Total Harmonic Distortion (THD) to 3.61% and after that again a PI controller is added to it to observe that betterment is achieved in THD again to about 1.11%.

Keywords: PI Controller, Kalman filter, Total harmonic distortion (THD), Neural network, Series Active power filter (APF)

1. Introduction

In contemporary years, the notion of power superiority has evicted to be further precarious in the electrical business. Stable voltage and fixed ac frequency near to the rated assessment or balanced voltage waveform or improved power factor are the physiognomies of worthy power quality. The occurrence of harmonics in power system can amend the voltage and current waveform and are able to furthermore alteration occurs in the rated ac frequency [3].

Harmonics denote to numeral multiples of the ultimate frequency and are instigated by non-linear loads similar to SMPS, Direct Current Converter, VFD, fluorescent tubes, inverters, etc. This task taken up distillates on the harmonic reduction in Variable Frequency Drive (VFD) which is engaged in practically all businesses as an electro-mechanical energy scheme. The inverter yield in the variable frequency drive trail comprehends harmonic currents. The vital frequency of generated harmonics is never from the frequency of applied power instead it is from the functioning frequency of inverter. Harmonics can pick up austere glitches in power system which may include excessive heat energy dissipation in the electrical devices, wrong identification meter output leading to inappropriate hike in customer bills, creating torque thumps in motor based equipment, interloping with phone trails and low-slung power factor [8].

A controller is a contrivance intended to pursue the alleviation of the gap amid the real value of a scheme, of course of the process trait, and the anticipated outcome from the implementation, which is what expected from the system. When coming to control engineering segment, controllers are the most crucial gadgets for getting the most complicated controlling done [2].

Proportional Integral Controller (PI Controller) is an arrangement of a proportional and an integral organizer where the output, precisely called as the acting signal, similar to the outline of proportional and integral of the error pointer. When the proportion coefficient gets more, the yielding power will be lessened for the identical regulator fault. While considering the integration coefficient, its escalation will slow down the hoarded integration coefficient [2].

2. System Design

The implementation here has taken its path to escalate the mitigation of the harmonics and problem of reactive power done by Active Power filter by using a neural network which is based on Kalman filter and later a PI controller is added to the same system of circuit. All the three scenario is being simulated in Matlab/Simulink to compare and conclude on possible betterments available with the approach [1],[2].

2.1. Series Active Power Filter

While considering a series Active Power Filter, there will be serialized link among the load and the AP filter. Only a reduced occupying area is necessary for obliging a series AP filter. The budgetvalue and affluence of execution also styles it a pertinentselection. It is predominantly made use of in alleviating voltage harmonics and further more to shield subdue load from voltage falsifications [7]. The figure
Kalman filters are a procedure intended for providing guesses of a few unidentified variables by considering the available dimensions perceived during a period of time. Kalman filters can be seen to be establishing its practicality in numerous solicitations and have comparatively guileless practice and necessitate minor computational clout. By linear prototypes with stabilizer Gaussian noises, the Kalman filter delivers ideal approximations while the protracted Kalman filter is employed for nonlinear complications like bearing-angle target chasing or Terrain-Referenced Navigation (TRN) [9].

Kalman filters which are made use of for estimating states depending upon linear dynamical systems in state space layout. The procedure model outlines the progression of the state starting at time $k-1$ to time $k$ as:

$$x_k = Fx_{k-1} + Bu_{k-1} + w_{k-1}$$

The term $F$ is the state transition matrix given to the aforementioned state vector $x_{k-1}$, $B$ is the control-input matrix provided to the control vector $u_{k-1}$ and $w_{k-1}$ is the process noise vector which is implicit to be zero-mean Gaussian having the covariance $Q$, i.e., $w_{k-1} \sim N(0,Q)$ [9].

The process model is combined with the dimension model proposed to designate the affiliation among the state and the capacity at the current time step $k$ as:

$$z_k = Hx_k + v_k$$

Here $z_k$ is the measurement vector, $H$ is the measurement matrix, and $v_k$ is the measurement noise vector which is presumed to remain zero-mean Gaussian having a covariance $R$, i.e., $v_k \sim N(0,R)$ [9].

The part of the Kalman filter is to deliver approximation of states $x_k$ at instance $k$, specified the preliminary appraisal of $x_0$, the sequence of measurement, $z_1, z_2, ..., z_k$, and the data of the organization pronounced by $F, B, H, Q$, and $R$ [9].

### 2.3. Neural Network Controller

The rudimentary structure of a feed forward neural network with dual layers, specifically a hidden layer and an output layer made use of in this execution is depicted below as figure 3; the feeds are multiplied with weights $W_i$ and added up to the biases, $b_i$.

![Double Layer Neural Network](image)

**Figure 3:** Double Layer Neural Network

In this effort, the neural network is fed with the state vector figured by means of Kalman filter. The neural network output layer will hold any of the binary values, i.e., 0 or 1. The neural network is educated expending the back-propagation procedure. The hidden layer encompasses of ten neurons through sigmoid activation function. The neural network yield part is attached to a pulse width modulation (PWM) generator use to regulates the swapping of power transistors within the structure of series active power filter and after that the voltage is produced to recompense the harmonic constituents [5], [6].

### 2.4. Proportional Integral [PI] Controller

A PI Controller is a feedback regulating hoop that gauges an error waveform after taking the difference among the output of a scheme, which in this circumstance is the power that is taken from the power source (battery) and the set point [10].

![PI Control Loop](image)

**Figure 4:** PI Control Loop [10]

The set point is the part at which from where the system is getting its feed and idly the executed scheme has taken its working nigh to a max power (990W) deprived of instigating the controller to involve. The figure depicted above has illustrated the loop structure of a PI controller; set point is seen and an error is fed to both the blocks to reach the system [10].
It is imperative to poke into that owing to the intricacy of the electronic apparatuses inside the circuit lane like ESC or motor or power limiter, an precise transfer function for the scheme was very tiresome to be modeled; thus using the trial and erro method parameters was made to be implemented [10].

3. System Implementation

A method for controlling an active power filter using neural networks is presented which is based on Kalman filter and an additional PI controller is added for additional escalation in enactment efficiency. A number of researches shows, it is visibly evident that an increase of voltage and current harmonics in power systems is triggered by nonlinear loads; the active power filters (APFs) are made use of to compensate the spawned harmonics and to resolve the load power factor [1], [4].

Figure 6: Full Model with Kalman Filter and ANN +PI

The circuit diagram kept above shows the setup made for the implementation of the scheme which will employ Kalman Filter depending Neural Network along with Active Power Filter first and then add an additional PI controller component for achieving an augmentation in output performance.

Figure 7: Voltage and current Output

The waveform above obtained by the simulation of the circuit in Matlab/Simulink shows the Voltage and Current output from the circuit during various instances of its execution. The first and second ones are obtained when there is not any compensating gadget is connected to the grid. The third shows output of voltage and current when Active Power Filter is connected serially to the grid.

While implementing the simulation of circuit without any recompense attached, the following graphical values of Total Harmonic Distortions [THD] was figured out.

Figure 8: Total Harmonic Distortion without Compensation

Figure 9: Total Harmonic Distortion with ANN

But after attaching an active filter with neural networkd which is dependent on Kalman Filter a considerable difference is seen in THD, which represented graphically below.

Figure 10: Total Harmonic Distortion with NN + PI
Figure 10 shows the simulated result of THD from the circuit having serially connected Active Power Filter with both neural network and PI controller.

4. Results

The implemented scheme had its output with identified betterment figures in terms of THD determined when compensation factors were added in two levels; the percentage values obtained are kept in the table below:

<table>
<thead>
<tr>
<th>Compensation Status</th>
<th>THD in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Compensation</td>
<td>11.78</td>
</tr>
<tr>
<td>With Neural Network without PI Controller</td>
<td>3.61</td>
</tr>
<tr>
<td>With both Neural Network and PI Controller</td>
<td>2.58</td>
</tr>
</tbody>
</table>

The tabular info above gives a significant support to the capability of Active Power Filter attached in series with the circuit along with Kalman Filter based neural network by reducing THD by 8.17% [1]. And when an additional PI controller was introduced to the system an additional 1.03% reduction was obtained in THD.

5. Conclusion

The harmonics created by a non-linear load was evidently diminished to a very low value in comparison to its situation where no recompensing part was attached. By utilizing a series Active Power Filter (APF) harmonics came under control and the addition of controlling feedback to APF through a Kalman dependent neural network, superiority of power percentage of harmonics reached as low as 3.61% from 11.78%. Actual functioning witness the generation of sinusoidal values by filter which are having same scale but different phase to finally achieve a sinusoidal and non-sinusoidal values by filter which are having same scale but different phase to finally achieve a sinusoidal and non-distorted throughput. When the PI controller was attached to the system, additional betterment was apparent with the least harmonic distortion recorded as 2.58%. Over the foundation of the simulation results obtained through Matlab/Simulink, it can be resolved that, PI organized circuit accomplish reasonable reimbursement of line current. Subsequently, line current turns out to be sinusoidal, stable and in phase with the relevant source voltage and condenses the THD of the basis current lower than 5% limit. It is agreed from simulation upshot that the ephemeralenactment of the source current and DC part of capacitor voltage is enhanced for the PI controller with respect of the setting time and % hike/alleviation in DC link voltage.

References


Author Profile

Praseeja P (DOB: 02/03/1997) received the BTech degree in Electrical and Electronics Engineering from Al-Ameen Engineering College, Kulappully under Calicut University in 2018. Currently, doing M Tech in Electrical &Electronics Engineering from Al-Ameen Engineering College, Kulappully under KTU. Being a final semester scholar of MTech, completed the paper on “Kalman Filter based Neural Network Control Strategy with PI Controller for Optimum Performance of Series Active Power Filter”. Hope to enter teaching sector after the successful completion of PG, as it was always a passion to teach and learn.

Abdul Vahab P A received B.Tech in Electrical and Electronics Engineering from Calicut University and M Tech in Power Systems Engineering from Anna University, Chennai. Worked as Operator Assistant Engineer in K.S.E.B and is currently working as Assistant Professor at Al-Ameen Engineering College, Kulappully. Has published Journal papers on “Overcurrent and Earth fault Relay Coordination for Microgrids with Modern Numerical Relay Features[NCIESM 2016]” and “Optimal Relay Coordination with DG Utilising Modern IED Features [NGCA 2016]”