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Intelligent SHE Controller for Single Phase Power Electronic Inverter

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***Abstract*— Harmonic Elimination in the output voltage of inverters is an important consideration as the presence of harmonics result in several undesirable secondary effects along with distorted waveforms. Most of the off-line PWM techniques use Newton-Raphson method for determination of trigger pulse-positions. This paper uses a combination of Evolutionary strategies and Artificial Neural Networks for design of Intelligent Selective Harmonic Elimination (SHE) controller. The controller calculates the trigger pulse positions intelligently by searching in the given solution space bounded by the practical constraints. The result analysis shows a significant decrement in harmonic components, while improvement in the fundamental voltage component, effectively reducing the Total Harmonic Distortion.**

Keywords—Intelligent Controller, Harmonic Elimination, Inverter control, Neural Network

I. Introduction

Power system is increasingly getting polluted due to harmonics created by power electronic circuits at a faster rate. These harmonic voltages enter into the power system and disturb other loads connected to the network. They have an ill effect on the measuring instruments also, leading to mal-operation of protection devices along with a fauly load operation. The Power Quality and Reliability has become a major concern for electrical engineers. These harmonics are to be kept below a safe limit to avoid their detrimental effects and for maintaining power factor of the system. It requires their elimination or blocking at different levels by some means. Harmonic reduction and/ or elimination is a problem constantly faced by electrical engineers. This topic has attracted a continuous research. Many techniques are employed for the elimination/mitigation of harmonics in case of converters and inverters, e.g. use of filter circuits, the sampling techniques, PWM variations etc. to name a few [1-4]. The research in this area has replaced the use of passive filters by active filters. An Active filter comprises of a power converter and a control loop, which controls the harmonic injection of the filter as a function of harmonic signal measure. These circuits compensate voltage or current harmonics by permanently injecting the pre-determined harmonic signal. The PWM variations are considered for harmonic elimination[5,6].

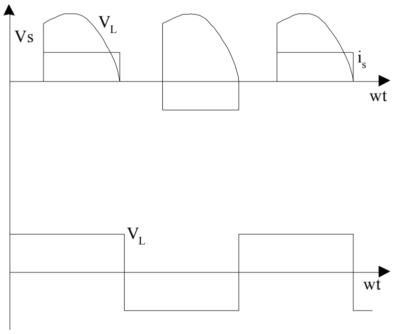
It is observed that the conventional numerical techniques are not able to give proper results as non-linearity is involved in the output voltage expressions of the inverters. Harmonic Reduction and or Elimination is an optimization problem which belongs to that class of optimization for which exact solution is not available using classical numerical methods or algorithms. This necessitates the implementation of artificial intelligence techniques, which include – Fuzzy Logic, Genetic Algorithms, Evolutionary Programming and Artificial Neural Networks[7-10]. These methods can efficiently handle highly constrained complex engineering problems as well as complex combinatorial optimization problems.

II. Pulse Width Modulation Technique

Pulse Width Modulation is a popular Technique used for harmonic reduction in power electronic converters and inverters. It offers an advantage of reduction in cost and size of filter circuit without using an extra component. The output voltage/ input current waveform for a single phase inverter/ converter is as shown in Figure 1.

Fourier series representation of this waveform would be:

$$Vo = \sum_{n}^{\infty} An * \operatorname{Sin} n * wt + \sum_{n}^{\infty} Bn * \operatorname{Cos} n * wt \qquad (1)$$



Where, n = 1,3,5,..

Fig. 1: Waveforms for a) Output Voltage & input current for a single phase

Converter

b) Output Voltage of a single phase inverter

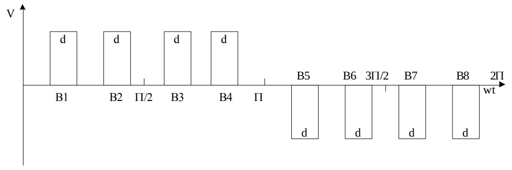


Fig. 2: Modulated Voltage Waveform for Selective Harmonic Elimination

A. *Selective Harmonic Elimination*

A process of Selective Harmonic Elimination (SHE) selects suitable pulse positions per quarter cycle to eliminate any M harmonics. The current or voltage variations are obtained by controlling the pulse-width symmetrically around these pulse-positions. Principally, all the pulse-widths are arranged to be equal as shown in fig.2. Quarter wave symmetry reduces the above-mentioned non-linear transcendental equations to the following form:

$$Vo = \sum_{k=1}^{M} 4V/n\Pi \int_{B_k-d}^{B_k+d} \sin n^{*}wt \, d(wt) \qquad (2)$$

Where, $B_k = k^{th}$ Pulse-position

$$Vo = 8V/n\Pi \sum_{k=1}^{M} \sin n^{*} d \sin n^{*} B_k \qquad (3)$$

Where,
$B_k = k^{th}$ Pulse-position
n = Harmonic numbers to be eliminated,
M= Total number of harmonics to be eliminated
V_o= Output voltage of inverter
d_k= Pulse-width of the respective pulse

Thus, M harmonic components of voltage or current can be eliminated by equating equation (3) to zero The problem gets converted into obtaining different pulse positions B_k This equation results in M non-linear algebraic simultaneous equations with 2M unknowns. Conventionally, this system of equations is solved by Newton-Raphson numerical technique with the assumption of equal pulse width for all the pulses. For elimination of complete lower order of harmonics, i.e.3rd, 5th,7th ,9th & 11th harmonic components, there will be a set of five simultaneous equations as shown below:

$$\sin 3B1 + \sin 3B2 + \sin 3B3 + \sin 3B4 + \sin 3B5 = 0$$

$$\sin 5B1 + \sin 5B2 + \sin 5B3 + \sin 5B4 + \sin 5B5 = 0$$

$$\sin 7B1 + \sin 7B2 + \sin 7B3 + \sin 7B4 + \sin 7B5 = 0 \qquad (4)$$

$$\sin 9B1 + \sin 9B2 + \sin 9B3 + \sin 9B4 + \sin 9B5 = 0$$

$$\sin 11B1 + \sin 11B2 + \sin 11B3 + \sin 11B4 + \sin 11B5 = 0$$

Newton Raphson method requires initial graphical approximation for its mathematical start for solving the differential function. Successive approximations and substitutions give final results. This harmonic minimization and fundamental voltage maximization problem is translated into an optimization problem producing the optimum trigger pulse positions and pulse-widths by using a combination of problem solving systems based upon real life brain activity where a living being responds to the new changes in its environment on the basis of its learning from the previous experiences and a system based on the principle of natural evolution and heredity i.e. the Neural Networks and Genetic Algorithms/ Evolution Strategies.

III. Intelligent SHE Controller

An Intelligent Selective Harmonic Elimination (SHE) Controller is a combination of Hopfield Neural Network and an Evolution Program. It searches for the required solution in the given solution space bounded by constraints.

A. *Hopfield Neural Network & Evolution Program*

The Artificial neural network is an association of different neurons capable of information transfer, which collectively represent a system model. An artificial neuron is designed to imitate the first order characteristics of a biological neuron. Fig. 3 demonstrates the biological neuron while fig. 4 shows a typical signal processing unit for an artificial neuron.

A continuous Hopfield Neural Network is designed for the optimization of a set of non-linear transcendental equations given by (1) and (2). Fig. 5 shows the Hopfield network corresponding to five pulse-positions. The set of equation mentioned above are converted into an optimization equation set-

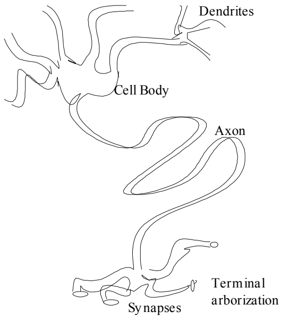


Fig. 3: Biological Neuron

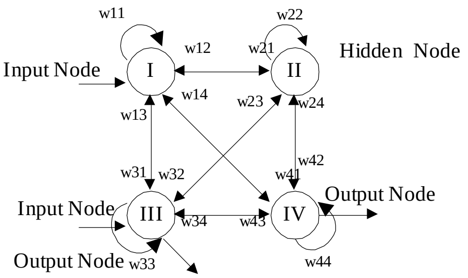


Fig. 4: Typical Processing unit for Artificial Neuron

$$\text{Min}\,(Fk) = \sum_{k=1}^{M} \sin n^* \, d \sin n^* \, B_k \qquad (5)$$

Where, Fk = Output to be optimised

The network equations are represented by (6) subject to given constraints

$$B_{p_{k(t+1)}} = n^* \text{sgn}\Big(\sum_{j=1}^{M} W_{kj} \; B_{p_{j(t)}} + B_k \qquad (6)$$

For $0 \le B_k \le \Pi/2$, Where, $B_{p_{k(t)}}$ represents an array of pattern

$B_{p_{j(t)}}$ = activation of the j^{th} neuron at time t,

B_k = Self –bias.

W_{xy}= connection weight between neuron x and neuron y
$W_{xy} = W_{yx}$ for continuous Hopfield network for Energy Minimization function.
n = learning rate of the network,
sgn = 1/(1-exp(-B)), Sigmoidal function
$-0.7 \le W_{xy} \le 0.7$

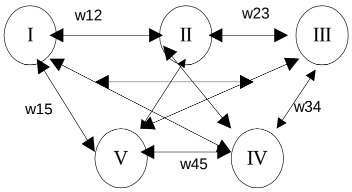


Fig. 5: Hopfield Neural Network

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Initialize the population P (0);
while termination condition is not satisfied,
Do
Determine potential parents from current population P(t);
Apply evolutionary operators, yielding offspring O(t);
Obtain P(t +1) from P(t) U O(t);
end-while;
Return best candidate solution from current population.
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Fig. 6: Algorithm for Evolution Program

The neural network is used to obtain pulse-positions such that the value of function F_k will be minimized. The node values are updated based on its instantaneous net weighted input. Fig. 6 shows the algorithm for Evolution Program. Evolution Strategies imitate the principles of natural evolution of living beings like survival of the fittest, transfer of hereditary characters from the parents to offsprings through chromosomes, changes in properties and behavior due to change in gene pattern as a result of crossover and mutation of chromosomes etc. for parameter optimization problems. An Evolution Program is used to obtain appropriate connection weights between various nodes. The connection weights are optimized using the Evolution Program.

IV. Experimental Results

Pulse-positions given by the conventional Newton-Raphson method are listed in Table 1. Table 2 lists a few pulse-positions given by Hopfield neural network.

TABLE 1: PULSE-POSITIONS OBTAINED USING N-R METHOD

Harmonics to be eliminated	3rd	5th	7th	9th	11th
Pulse-positions (angles in radians)	0.386	0.94	64.2	1.12	1.45
Pulse-positions (angles in radians)	0.41	0.97	1.13	1.25	1.51

TABLE 2: A SET OF PULSE-POSITIONS GIVEN BY ANN

Harmonics to be eliminated	3rd	5th	7th	9th	11th
Pulse-positions (angles in radians)	0.34	0.59	0.85	1.35	1.52
Pulse-positions (angles in radians)	0.36	0.82	0.93	1.12	1.44

Trigger pulses produced at the pulse-positions given by both techniques resulted in variation of harmonic components and Total Harmonic distortion. It is observed from the graph shown in fig. 7, that the ANN pulse-positions give better harmonic reduction as compared to that obtained using the N-R pulse-positions. The output voltage of ANN controlled inverter is given to a 200 W, 230V, 50 Hz single phase Induction motor in MATLAB simulation as shown in the block diagram of fig. 8. The pulse-positions and output voltage of inverter are as shown in fig. 9 while fig. 10 shows the waveforms for NR controlled inverter.

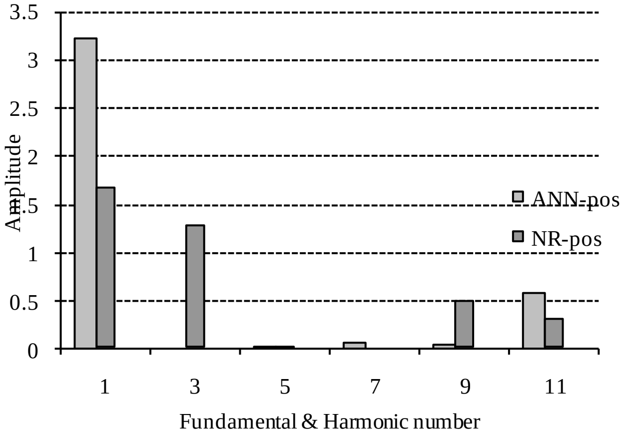

Fig.7: Comparison of Fundamental & other harmonic voltages

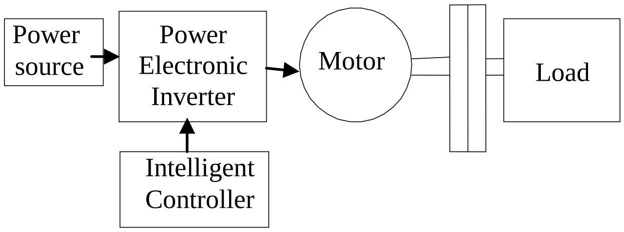

Fig. 8: Block Diagram Of Inverter Feeding Motor Load

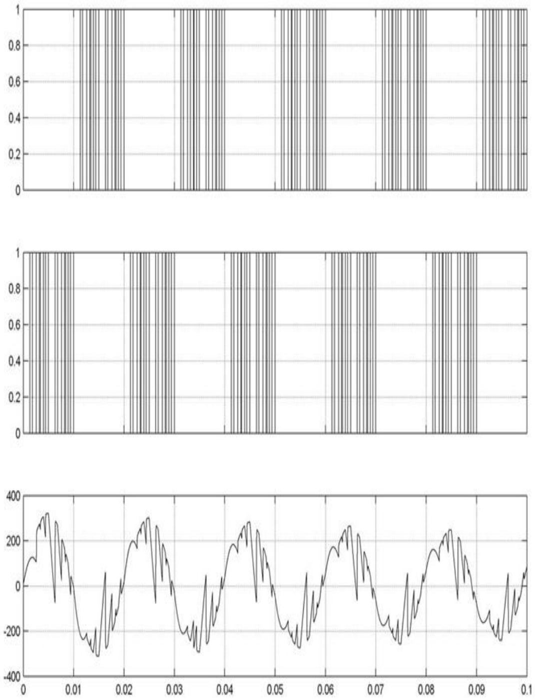

Fig.9: Trigger Pulses and Output voltage of Ann controlled Inverter

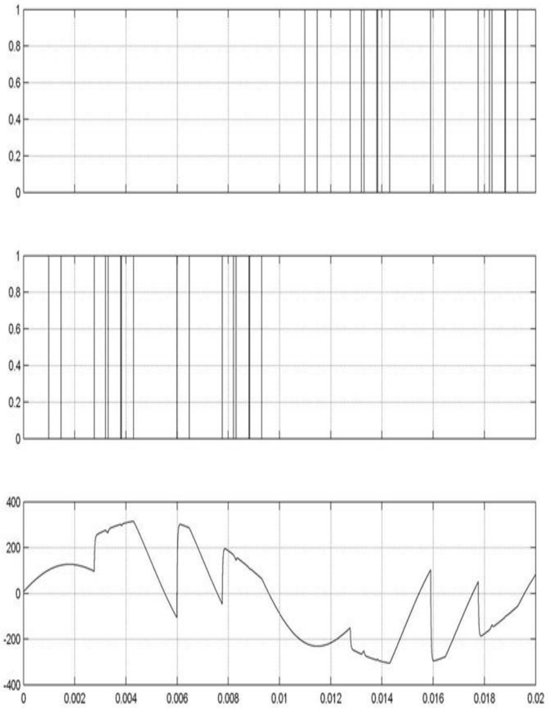

Fig. 10: Trigger pulses and output voltage of NR-controlled Inverter.

It is observed that the voltage applied to stator in case of Intelligent SHE controlled Inverter is higher than that in case of NR-controlled Inverter resulting in better performance of the Induction motor as is seen from Table 3.

TABLE 3: INVERTER VOLTAGE AND TORQUE PRODUCED BY INDUCTION MOTOR RUNNING AT SLIP OF 5%

Intelligent SHE controlled inverter	Inverter Voltage = 177.4 V	6.66 Nm
NR-controlled inverter	Inverter Voltage = 156.6V	5.9 Nm

V. Conclusion

It is observed that the trigger pulse-positions given by intelligent SHE controller produces better quality of voltage at the Inverter output as is seen from MATLAB simulation as compared to that obtained by the conventional numerical technique of Newton-Raphson method. The Intelligent SHE controller can handle the complex non-linear transcendental equation set in a better manner producing the optimum trigger pulse-positions. It is further observed that the Induction motor load is also delivering better performance when driven by Intelligent SHE controlled Inverter.

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