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BOOST PFC PI CONTROL BY USING HEURISTIC OPTIMIZATION METHOD

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Abstract- In this study, Proportional Integral (PI) control of a one-cell boost power factor correction (PFC) converter is realized. PI control coefficients are derived by using heuristic method. The transfer function of the system is obtained in classical control methods and according to this transfer function, control coefficients are derived by using trial and error process. This process is started with random method and coefficients are adjusted according to dynamic response. Ziegler Nichols, Cohen Coon, and Internal Mode Control Methods are in this type of control methods. Procedures in these methods are time consuming and dynamic response is not good. Especially in control systems, which have two or more than control loops, this methods' efficiencies aren't enough. The scope of this study is to derive PI control coefficients of two control loops of PFC system by using heuristic methods. Genetic Algorithm (GA) is selected as test bed. By this way, control coefficients will be derived synchronously and in smaller time. Also results will be better than other PI control tuning methods used works.

Keywords: Genetic Algorithm (GA), Proportional Integral (PI) Control, Power Factor Correction (PFC).

I. INTRODUCTION

The numbers of power conversion topologies and power densities used in industrial devices and home equipment have increased importantly in recent years. Obtaining efficiency in electrical power conversions has been an important topic beside improvement in topologies and sizes in electric and electronic technology field. DC voltage is used by most of electronic equipment for work. AC voltage has taken from the utility and it is converted to DC voltage. A diode bridge rectifier circuit realizes this AC-to-DC conversion.

In this traditional rectification method, the input current incorporates pulses, so it is not a purely sinusoidal signal. The current quality deteriorates as a result. The power factor (PF) decreases and total harmonic distortion (THD) increases. In active methods used power factor correction applications, boost converter is the most common topology. Continuous current is drawn from converter input inductor.

This topology's main advantage is this. The disadvantages of this topology are having high overshoot on output voltage and requiring a second converter to lower the output voltage. Average current controlled boost power factor correction circuit has two control loops. While outer control loop is providing voltage regulation, inner control loop produces switching signals. Output voltage sampled and used for producing current reference signal. Current reference signal and converter input inductor current compared and switching signal of the switching device produced according to current error signal.

For obtaining desired voltage level and high power factor, outer and inner control loops should be controlled efficiently. Despite the potential of the modern control techniques with different structure, PID type controller is still widely used in power converters [1-2]. This is because it performs well for a wide class of process. In addition, they give robust performance for a wide range of operating conditions and easy to implement. The optimal tuning of PID gains is required to get the desired level of robust performance since optimal setting of PID controller gains is a multimodal optimization problem (i.e., there exists more than one local optimum) and more complex due to nonlinearity, complexity and time variability of the real world power systems operation.

In this work, PI control is used for both control loops. PI coefficients are derived by using heuristic optimization method. Algorithm starts with a random initial solution group in these methods. These candidate solutions are updated during iterations and the best solution that performs the problem requirements satisfactorily held. Computational complexity is lowered by using these methods. It is used genetic algorithm (GA) as heuristic method. In this paper, the principle of the average current controlled boost power factor correction circuit explained in section II. Genetic Algorithm (GA) is discussed in section III. Simulation results based on performance analysis are shown in section IV. The work is concluded and information about future works is given in section V.

II. CONTROL METHOD OF BOOST PFC CIRCUIT

For converting DC-DC signal level, many power configurations have evolved. The most common topology is boost converter for power factor correction. This circuit topology is illustrated in Figure 1. The topology is used to obtain greater output voltage than the input voltage. There is not any distortion in the input voltage near zero points like in buck converter.

The circuit can be operated in switch mode from zero point to peak point of input voltage as a result of this situation. Input current waveform can track the input voltage waveform in that way. Both amplitude and phase of impedance are modulated by duty ratio of the switching device. That means the better control of input current and output voltage. Occurrence of EMI is less in this topology than other DC-DC converter topologies.

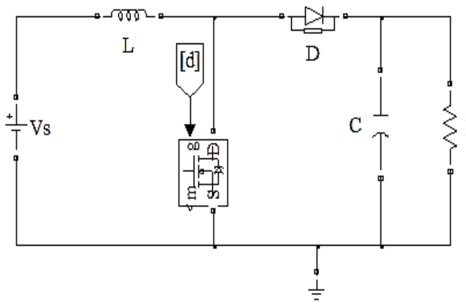

Figure 1. Boost converter topology

Current control and voltage control can be classified as PFC control techniques. The main objective of power factor correction is tracking the input current to line voltage waveform, so current control is more common in power factor correction applications. Average current control is the most suitable method for current control in power factor correction. A boost power factor correction circuit using average current control has shown in Figure 2.

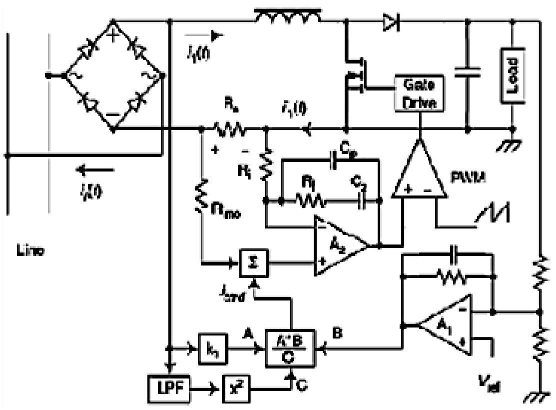

Figure 2. Average current controlled boost type PFC converter

Comparing with peak current control input current waveform is improved. Inductor current is tracked instead of switch current in average current control. Inductor current is compared with produced reference current and switching is done due to their difference. So, average of input current tracks average of reference current. On and off positions of switching device are adjusted by pulse width modulation (PWM).

Inductor current is sensed and its output is filtered in average current control method. Therefore, error of inner control loop is worked to minimize. This control technique is preferred due to reasons like immunity to noise and low input ripple. Disadvantages of this technique are the necessity of controlling inductor current and designing current error amplifier. Average input current waveform is shown in Figure 3 when average current control method is used. In this figure, I_{avg} symbolizes input average current signal.

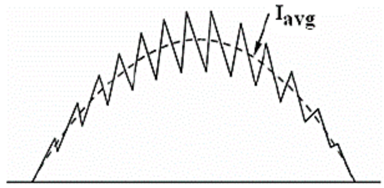

Figure 3. Input average current signal

III. GENETIC ALGORITHM

The results of a process are related to its control system performance. PI control is one of the most common methods in industrial applications. This control technique is reliable and has a simple structure. PI control coefficients in power factor correction have influence on power factor, total harmonic distortion, overshoot, undershoot, rise time, settling time and steady state error. The prior aim of power factor correction is to increase power factor and to decrease total harmonic distortion.

PI control coefficients can be held by using empirical tuning methods like Ziegler Nichols (ZN), Cohen Coon (CC), and Internal Model Control (IMC) methods. Random values are assigned to control coefficient parameters and tuning of these parameters is realized according to dynamic responses. Overshoot, undershoot and settling time are high and load disturbance response is bad when these methods were used. Parameter tuning is a time consuming procedure because of trial and error process [4].

PI control coefficients can be held by optimization methods instead of empirical methods. Gradient-based optimization is the first choice. Derivative information of the error function is used and local minimum point is searched. This method has a computational complexity and it's a time-consuming procedure because of the mathematical computations. Using heuristic methods in optimization is the second choice. Algorithm is started with a random initial solution group in these methods. These candidate solutions are updated during iterations and the best solution that performs the problem requirements satisfactorily is held.
Computational complexity is lowered by these methods. It is used genetic algorithm as a heuristic method in this paper. Genetic algorithm is a parallel and global search technique developed by John Holland in 1975 [5]. It is based on biological evolution and survival of the fittest individual principal [6]. The pseudo code of genetic algorithm is given in Figure 4. According to Equation (1) the creation of the population with random method.

```
DO
    FOR every chromosome in population
    Coding
    Evaluate of the fitnesses of every chromosomes
    (according to Equation (2))
    Selection of parent chromosomes to crossover
    Deriving child chromosomes by crossover operation
    from selected parent chromosomes (according to
    Equation (3))
    Mutation to child chromosomes
    Decoding
    Evaluate of the fitnesses of child chromosomes
    IF fitnesses of child chromosomes are better than
    fitnesses of parent chromosomes
    Replacing child chromosomes with parent chromosomes
    END
WHILE maximum iteration or minimum error criteria is not
satisfied
```

Figure 4. Pseudo code of GA

In genetic algorithm, "population" calls potential solutions and "individual" calls each of the solutions in population. "Chromosome" is coded version of problem solution that noted by individual. Chromosomes are specified by bits, characters or number strings. The aim of problem solution in genetic algorithm, obtaining the best solution that provides all the constraints of the problem. Selection, crossover, and mutation steps do this process during iterations to possible solutions.

Population dimension, population size, iteration number, limit values, crossover ratio (CR) that can been taken by chromosomes are initialized at the start of the algorithm. In PI controlled boost power factor correction converter, current K_p, current K_i, voltage K_p and voltage K_i values are required to obtain. So the population dimension is 4, population size is 20, iteration number is 30, upper limit of Current K_p is 1, upper limit of current K_i is 1500, upper limit of voltage K_p is 0.01 and upper limit of voltage K_i is 1.5. Lower limits of chromosomes are 0 and CR is 0.9. Initial vectors can be produced by Equation (1).

$$\begin{cases} \forall_i < NP \quad \text{and} \quad \forall_j \le D: \\ x_{j,i,G=0} = x_j^{(l)} + \text{rand}_j\,[0,9]\left(x_j^{(u)} - x_j^{(l)}\right) \end{cases} \tag{1}$$

where, NP is population size, D is population dimension, $x_{j,i,G}$ is jth parameter of ith vector at Gth generation. $x_j^{(u)}$ and $x_j^{(l)}$ are representing upper and lower limits of variables respectively.

Random number between 0 and 9 is produced for jth parameter of the vector by $\text{rand}_j[0,9]$ term. The reason of choosing this interval is that coding procedure done in floating point representation in decimal arithmetic in this paper. Coding procedure is the section how genes in chromosomes will be represented. After coding procedure is done, the fitness values of every chromosomes are evaluated. In this step of the procedure, the simulation program tests candidate solutions and it studies to minimize the cost function. Cost function is a function that relates to performance of the system.

For a power factor correction application, voltage and current errors and total harmonic distortion should be minimized. Therefore, power factor will be higher and total harmonic distortion will be lower. According to these situations, cost function formed as in Equation (2).

$$\begin{aligned} \cos t &= ((\text{mae}(current\_error))/load\_current) + \\ &+((\text{mae}(voltage\_error))/load\_voltage) + \\ &+(\text{mae}(THD)) \end{aligned} \tag{2}$$

where, 'mae' is a function in MATLAB program that calculates average value of absolute error for one period. When Equation (2) is minimized, the performance will be higher as a result.

If a chromosome has a lower cost value, it means that chromosome has a higher fitness value. The selection chance of chromosome for crossover is high if it has a better fitness value than others. Chromosomes that have better fitness values are select and putted in mating pool for crossover. This selection mechanism is called tournament selection. There are also methods like proportional selection, roulette wheel selection, stochastic universal sampling, and general elitism in literature. In tournament selection mechanism, it is applied pressure to mate of individuals, which have higher fitness values and it is hoped that child chromosomes would have higher fitness values than their parents at the end of this step.

After selection procedure has done, crossover mechanism has started. In this step of algorithm, it is started to create child chromosomes by crossing selected chromosomes. Two child individuals are created by crossing two parent chromosomes, which have selected by tournament selection. The aim of crossover process is to produce child chromosomes from parent chromosomes that will have better fitness values than their parents. Arithmetic crossover is done in this paper according to Equation (3) [6].

Chromosome with CR ratio is taken from first parent and chromosome with (1–CR) ratio has taken from second parent. First child has produced in this way. In a similar way, chromosome with (1–CR) ratio is taken from first parent and chromosome with CR ratio has taken from second parent to produce second child [7].

$$\begin{cases} A_1 = CRX + (1-CR)Y \\ A_2 = (1-CR)X + CRY \end{cases} \tag{3}$$

where, A_1 is first child, A_2 is second child, X is first parent and Y is second parent in this formula.

Mutation procedure is held after crossover. A certain part of genes of child chromosomes mutate with determined amount in this step of algorithm. This procedure is realized by inverting of bit values when coding has done in binary system. The method is taking 9's compliment of the step that selected to mutate in decimal arithmetic representation [8]. Decoding procedure is done to derive the real value of chromosomes by evaluating step-by-step represented chromosome after mutation. Evaluation of child chromosomes is done by putting the real values of chromosomes in cost function. If a child chromosome have a better fitness value than a parent, it takes the place of that parent [9].

Survival of better ones has done in that way. If maximum iteration number or minimum error criterion has reached, the algorithm is finished. Otherwise, it has turned to coding step and algorithm continues from here.

IV. PERFORMANCE ANALYSIS

In this study, a boost power factor correction converter, which has 400 V output voltage and 1 kW load, is used for test bed. Inductor value is 6.8 mH and capacitor value is 500 µF. In addition, it is studied with another boost power factor correction circuit, which has different parameters, to verify the validity of cost function. This system has 600 V output voltage and 2.4 kW load. Load current and load voltage values of cost function are updated for normalizing procedure for new output voltage and load condition. The validity has been proven by the results and thus, investigations have continued on the main test bed. When genetic algorithm has used to derive PI control coefficients in boost power factor correction test bed, control coefficients in Table 1 are obtained.

Table 1. PI Control coefficients (GA using)

Controller parameters	Value
Current K_p	0.9
Current K_i	829
Voltage K_p	0.0099
Voltage K_i	0.802

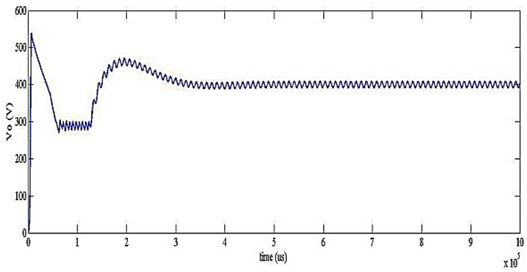

Figure 5. Output voltage

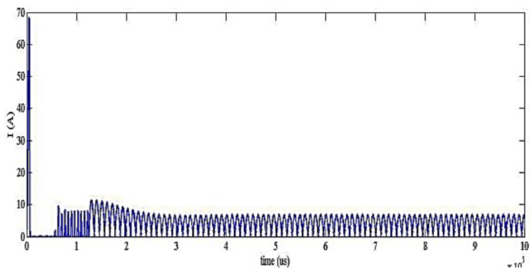

Figure 6. Input current

Output voltage and input current are illustrated in Figure 5 and Figure 6 respectively. They are obtained when coefficients in Table 1 have used. Source and load are changed, analysis are repeated and results are shown in Table 2. Load is 1 kW for 1st state, 2 kW for 2nd state and 0.5 kW for 3rd state and source voltage is 220 Vrms and 50 Hz for these conditions. Load is 1 kW for 4th state, 2 kw for 5th state and 0.5 kW for 6th state and source voltage is 110 Vrms and 50 Hz for last three conditions.

According to results in Table 2, power factor is high, total harmonic distortion is low and output voltage is set to reference voltage for all conditions.

Table 2. Performance analysis for different source and load conditions

State_1	*PF* = 0.9997, *THD* = 0.02604, V_o = 400 V
State_2	*PF* = 0.9997, *THD* = 0.02036, V_o = 400V
State_3	*PF* = 0.9995, *THD* = 0.03742, V_o = 400V
State_4	*PF* = 0.9999, *THD* = 0.02304, V_o = 400V
State_5	*PF* = 0.9999, *THD* = 0.0174, V_o = 400V
State_6	*PF* = 0.9998, *THD* = 0.02529, V_o = 400V

In addition, load-switching conditions are investigated. The load is increased to 2 kW from 1 kW at t = 0.5 second and decreased to 1 kW again at t = 1.5 second. Output voltage and input current are illustrated for this situation in Figure 7 and Figure 8, respectively. When load is changed, system can set at steady state in a small time interval as can be seen in the figures.

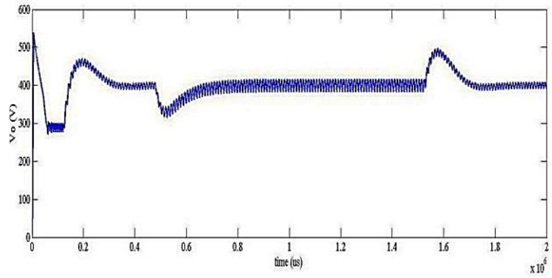

Figure 7. Output voltage for load switching

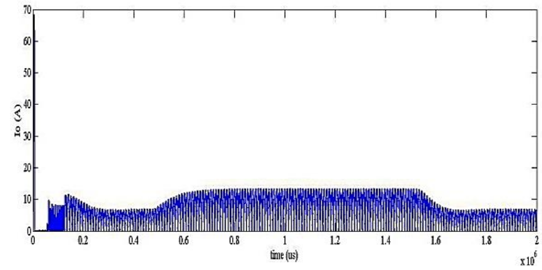

Figure 8. Input current for load switching

Dynamic responses are investigated and results are shown in Table 3. Overshoot is acceptable, rise time and settling time are small, output voltage ripple is low and there is no steady state error as can be seen in Table 3.

Table 3. PI Control coefficients (GA using)

Parameter	Value
Overshoot (%)	34.6
Rise Time (ms)	2.5
Settling Time (ms)	362
Output Voltage Ripple (%)	4.1
Steady State Error (V)	0

V. CONCLUSIONS

Genetic algorithm has proposed to optimal tuning of PI coefficients of a boost power factor correction converter in this paper. Firstly average current controlled boost power factor correction circuit is explained and its control strategy is discussed. In a power factor correction application, output voltage is sampled and compared with reference voltage. Difference between these signals are controlled by voltage control. Current reference signal is produced by using output of voltage control.

Reference current signal is compared with inductor current signal and according to difference between these signals, current control is realized and switching signal is produced. As explained above, power factor correction circuit has two control loops and outer loop produces reference signal for inner control loop. Therefore, control loops influence each other performance and control action should have enough efficiency. PI control has selected for two control loops in this study. Despite a lot of PI tuning formulas in literature, they are not efficient.

These methods are time consuming and dynamic responses are bad. The main aim of power factor correction application is increasing power factor and decreasing total harmonic distortion. It can be realized if control strategy is efficient. Genetic algorithm approach has suggested to derive PI control coefficients. A cost function has formed by taking into considerations of power factor correction application and candidate solutions have tested with this cost function by genetic algorithm. PI coefficients have derived and tested for different source and load conditions.

In addition, dynamic responses are investigated. According to performance analysis, power factor is high, total harmonic distortion is low, and voltage regulation has obtained for all conditions. It can be seen that dynamic response is good according to overshoot, rise time, settling time, output voltage ripple and steady state error parameters [10]. Future works will be based on realizing the study on hardware implementation, trying different heuristic methods like ant colony algorithm, particle swarm optimization, and hybridizing these heuristic methods with each other to compare performances.

NOMENCLATURES

CR: Crossover Ratio
GA: Genetic Algorithm
PF: Power Factor
PFC: Power Factor Correction
PI: Proportional Integral Control
PID: Proportional Integral Derivative Control
PWM: Pulse Width Modulation
THD: Total Harmonic Distortion
V_o: Output Voltage

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BIOGRAPHIES

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