International Journal of Research in Advanced Engineering and Technology
ISSN: 2455-0876
Impact Factor: RJIF 5.44
www.newengineeringjournal.in
Volume 4; Issue 1; January 2018; Page No. 09-15

Intelligent design of a high-frequency resonant power converter for electrostatic precipitator using a particle swarm optimization

Mostafa Jamalinia, * Pouya Derakhshan-Barjoei
Department of Electrical Engineering, Naein Branch, Islamic Azad Univesity, Naein, Isfahan, Iran

Abstract

Application of resonant converters has increased dramatically due to their advantages and characteristics. Resonant structures are much more useful compared to hard-core switches. These structures have many features like: high power density, high efficiency, high switching frequency, and low electromagnetic noise. In today's industries, there are many applications of Direct Current (DC) power supplies at high voltage levels. One of these applications is the Electrostatic Precipitator System (EPS). In different instances, the advantage of the high frequency switching function is to reduce the dimensions and weight of the installed equipment, having a direct current output voltage with low ripple, a very fast response control, and a high power supply in the charging point. In such systems, the control circuitry and proper design are one of the most recent challenges. In this paper, using a precise mathematical model derived from Thiago B. Soeiro's reference paper. At the first the characteristics, and structure of the resonance converter for feeding the electrostatic load have been described. Considering that the design of the resonant converter due to the dependency on the load and frequency of excitation is complex and timely work. In this paper we have investigated the application and optimization with the evolutionary Particle Swarm Optimization (PSO). Our goal is to optimize the power and efficiency of the converter and reduce the voltage stress of the circuit components. The results show that these parameters are improved by the proposed evolutionary algorithm.

Keywords: high frequency resonant conductor, parallel-series conductor, particle swarm optimization, electrostatic precipitators

1. Introduction

An example of industrial air filters that are used on many occasions are industrial Electrostatic Precipitators (EP), nowadays [1]. These filters require an appropriate and stable power supply. This paper reviews a LCC resonant converter to be supplied by industrial electrostatic precipitators. Compared to hard-switching converters, resonant structures have many advantages [2]. In resonance converters, the switching power loss coefficient is eliminated, and since the losses are proportional to the switching frequency, the resonance converters can operate at frequencies much higher than Pulsed Width Modulation (PWM) converters [3]. Due to the relationship between the operating frequency and the physical size of the system, these systems are smaller and less weighty. Among different structures, a Parallel-series resonator converter combines the advantages of a series resonant converter and a parallel resonator converter [3]. We must keep in mind that the control of resonant converters is very complicated due to their nonlinear dynamic state. Solving the problem of controlling high frequency converters is very important in practical applications. Different control strategies including linear and nonlinear methods are presented. Linear methods have good performance only at a one point of operation or quiescent point, while nonlinear methods have been developed for their transient response, robustness, and their stable behavior against load variations and input voltage changing [4]. Non-linear controller, in contrast to linear control methods, directly cops nonlinear effects and can be used in systems with unknown parameters. In reference [5], three types of switching patterns for three types of resonant converters have been studied in order to achieve the zero-voltage switching operation, which shows the superiority enhancement of parallel-series converter. Another point should be noticed that the existence factors such as: indeterminacy, noise, and distortion has always made it difficult to implement design of a controllers for practical systems. In order to deal with such factors, many attempts have been made to control nonlinear systems in various ways [6]. On the other hand, in recent years, high voltage direct current power supplies have been applied in many industries, including electrostatic precipitators [7]. One of the most widely applicable methods for producing high voltage power supplies is the use of resonant converters that causes a wide variety of its application. In these converters, because of the resonance property, the switches generally works in soft switching mode, and because of the absorption of parasitic elements in the resonant tank circuit, the effect of the presence of parasitic elements is eliminated [8]. On the other hand, the lack of the inductor in the output filters of high voltage converters does not allow to use an equivalent resistance in the output of the resonant inverter, and therefore the routine modeling of the resonant converters and the analysis of the first harmonic approximation cannot be used and the effect of the output filter capacitor on the behavior of the resonance converters should be considered. In reference [9], the control of voltage and output in resonance converters is carried out by using a common frequency control method and another method called dual control. In the first method, the output voltage is stabilized by the control of the resonant gain circuit by changing the switching frequency, but in the second method, the switching frequency is constant, and the output voltage is stabilized by controlling the first harmonic amplitude of the applied voltage to the input of the resonant circuit by changing the pulse width. Reference [4] refers to voltage control problems due to switching frequency, the most important note is the complexity of control circuit and optimality of output filter. On the other hand, there are many resonant topologies of varying degrees which are discussed in [10-12]. In reference [13], the advantage of the high frequency switching function to feed the ESP load is expressed in terms of reducing the dimensions and weight of the equipment, having a direct current output voltage with low speed, very fast response control, and high power in ESP power supply. Also, reference [7] provides a suitable method for improving the resonance converter to supply high frequency and high power direct current loads.

In this paper, using a precise mathematical model suggested by Thiago B. Soeiro's [13] and previous research, we describe the specification and structure of the resonant converter used to feed the ESP load. In our proposed method, we use an evolutionary particle swarm algorithm. In this project, after presenting the proposed structure, and presenting a proposed method for high frequency switching, we designed the converter with the use of evolutionary algorithm to increase the power and efficiency of the converter and reduce voltage stress. The optimal design of the resonant converter was carried out and the results of it were investigated.

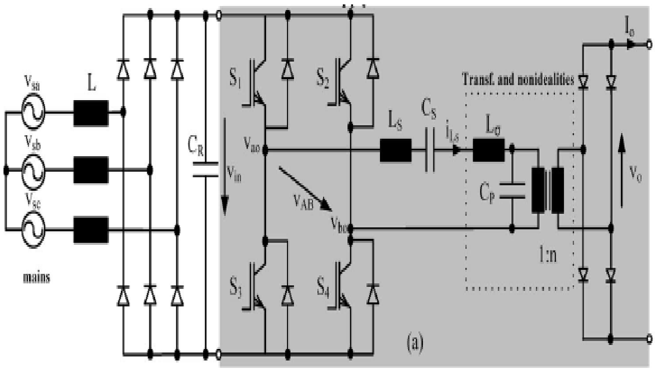
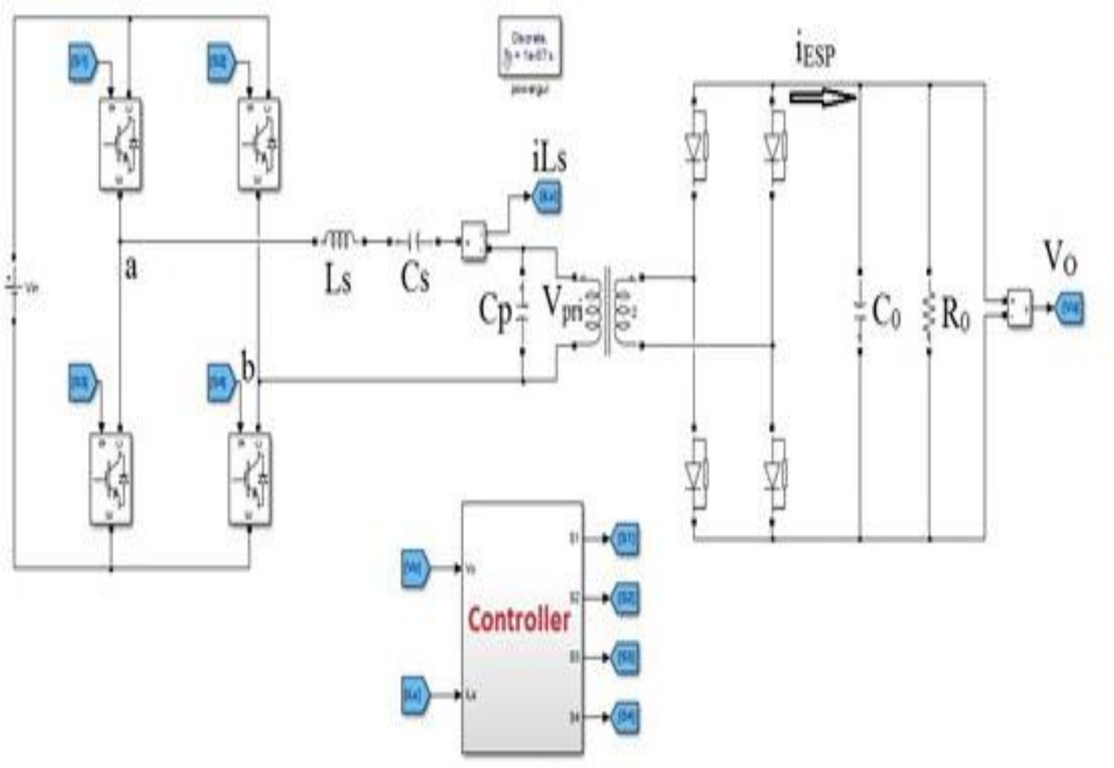


Fig 1: LCC resonant converter for feeding ESP [13]

2. Proposed Method and Simulations

In the past researches, there have been several techniques for optimizing design and operation in power systems. In this research, we study the particle swarm optimization algorithm. Considering that in these algorithms we do not need to calculate the derivative of the objective function and the probability of finding an optimal absolute solution in them is more than the classical algorithms. Regarding the circuit and simulations of the research in [13] we performed our optimization.



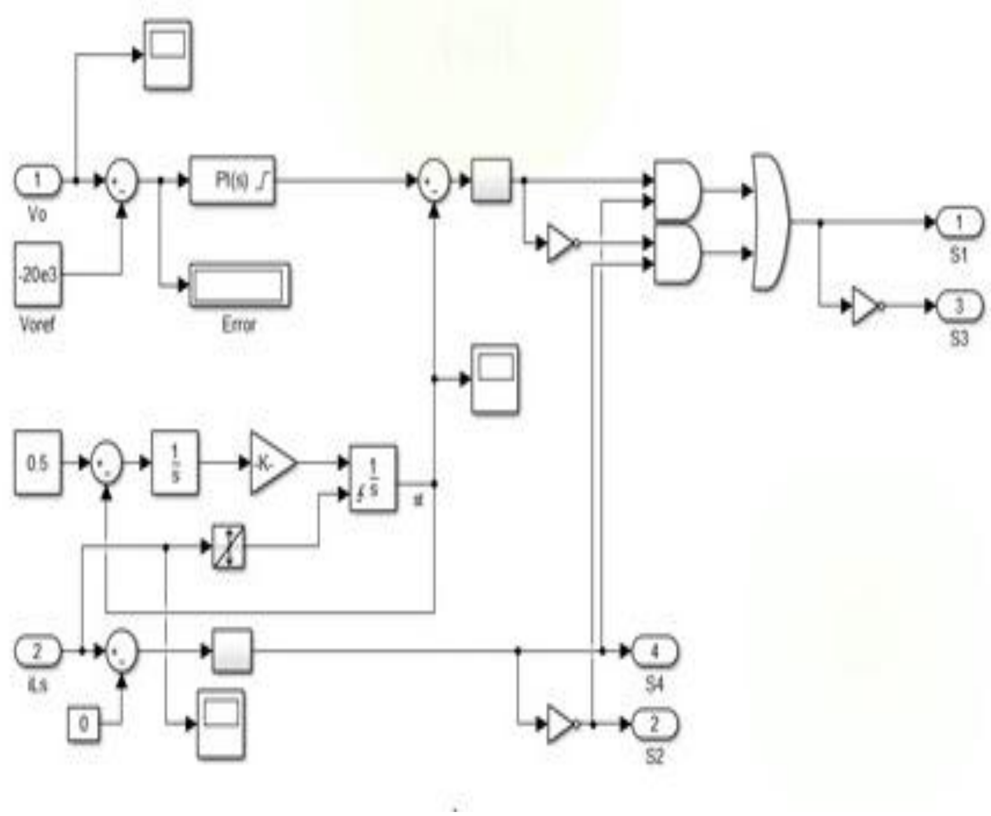


Fig 1: Block diagram of simulated resonant converter

2.1 Evolutionary Algorithm

Particle swarm algorithm is a social search algorithm inspired of social behavior of bird categories. Initially, this algorithm was used to explore patterns of flight of birds and their sudden change of direction. In the particle swarm algorithm, particles are flowing in the search space. The particle movement in the search space is influenced by the experience and knowledge of themselves and their neighbors. Therefore, the other particle mass influences how a particle is searched. The result of the modeling of this social behavior is the search process that particles tend to succeed. Particles learn from each other and based on their knowledge of their best neighbors. Each particle has its place in the search space according to the best place ever contained in it. And the best place to sit around in its entire neighborhood.

Swarm Intelligence is a systematic property in which the agents collaborate locally and the collective behavior of all agents leads to a convergence at a point close to the optimal global answer. The strength of this algorithm is the absence of a global control. Each particle (factor) in these algorithms has a relative autonomy that can move across the solution space and should work with other particles (agents). In 1995, Eberhart and Kennedy introduced the PSO as an indeterminate search method for functional optimization for the first time. This algorithm is inspired by the swarm movement of birds seeking food [18].

A group of birds in space are randomly looking for food. There is only one piece of food in the area in question. None of the birds knows where food is. One of the best strategies can be to follow a bird that has the least distance to the food. This strategy is in fact the source of the algorithm. Every solution is called a particle. Each particle has an arbitrary value calculated by a merit function. The more particles in the search space reach the goal, food is closer to the model of the movement of birds, it is more competent. Each particle also has a velocity that controls the movement of the particle. By continuing to pursue optimal particles in the present state, the agent continues to move in the problem space. It is in this way that a group of particles in an object are created randomly, and by optimizing generations, they try to find a solution. In each step, each particle is updated using the two best values. The first is the best situation ever achieved by the particle. The situation is recognized and maintained. The best alternative used by the pbest algorithm is the best position ever achieved by the particle population. This position is displayed with gbest [18].

2.2. Comparison of Algorithms

Different evaluation methods such as comparing the best answer, comparing the convergence rate, comparing the time of convergence, and comparing the number of function evaluation recall (NFE) call times are used to compare evolutionary algorithms. In most articles and references, the frequency of recalls to the objective function is introduced as a criterion for evaluating optimization algorithms, and an algorithm that achieves the optimal response with less number of recalls, the algorithm is more suitable for the desired problem. In Table 1, the values of the parameters of the LCC resonant converter is determined and its block diagram is shown in figure 2. The values mentioned are aimed at optimizing LCC resonance converter by reducing the component volume and reducing component losses, in this case, a maximum load of 60 kV and a minimum input voltage of 465 volts is calculated [13].

Table 1: Parameter of LCC Resonance Converters

Value	Parameter
42μH	Ls
1.4μF	Cs
120nF	Cp
10μF	C_0
6.67KΩ	R_0

3. Optimal controller design for LCC resonant converter and results

In this paper, the purpose is to determine the coefficients of LCC resonant converter controller presented in figure 2. It is to minimize the proposed objective function. It should also be noted that in this process, the particle swarm optimization (PSO) has been used. On the other hand, in each optimization algorithm, it is first necessary to select the variables that are intended to optimize the cost function, and based on them, find the desired result. In this paper, the selected variables for the PSO algorithm is determined in figure 2. Three variables have been selected for this simulation, the coefficients of integral, derivative and proportional are considered as K1, K2 and Kp. In the optimal design of LCC resonance converter, a particle swarm algorithm has been used to increase accuracy and obtain coefficients [17]. In table 2, parameters of the particle swarm algorithm are shown for optimizing LCC resonance transducer. It is worth noting that because of taking time of simulation of a LCC converter, it has been abandoned in the particle algorithm. In addition, the population of the algorithm with respect to the searchable space can be between 10 and 50, which is considered at least 10 in this simulation [19].

Table 2: Parameters for setting particle swarm algorithm

Number	Parameters
40	Iteration
10	Population

In Table 3, the values obtained for the LCC resonant converter are listed. The limits for the parameters listed in this table are selected according to reference [13].

Table 3: Adjusted Parameters of LCC Converters using PSO Algorithm

Results	Boundary	parameters
8.9738	0<K1<10	K1
0.0131	0<K2<10	K2
7.0546e8	0<Kp<1e10	Kp

The simulation result of proposed method is as follows; in figure 3, the output voltage of the LCR resonant converter, i.e., the two-phase resonant voltage, which is the same as the electrostatic precipitators, is shown.

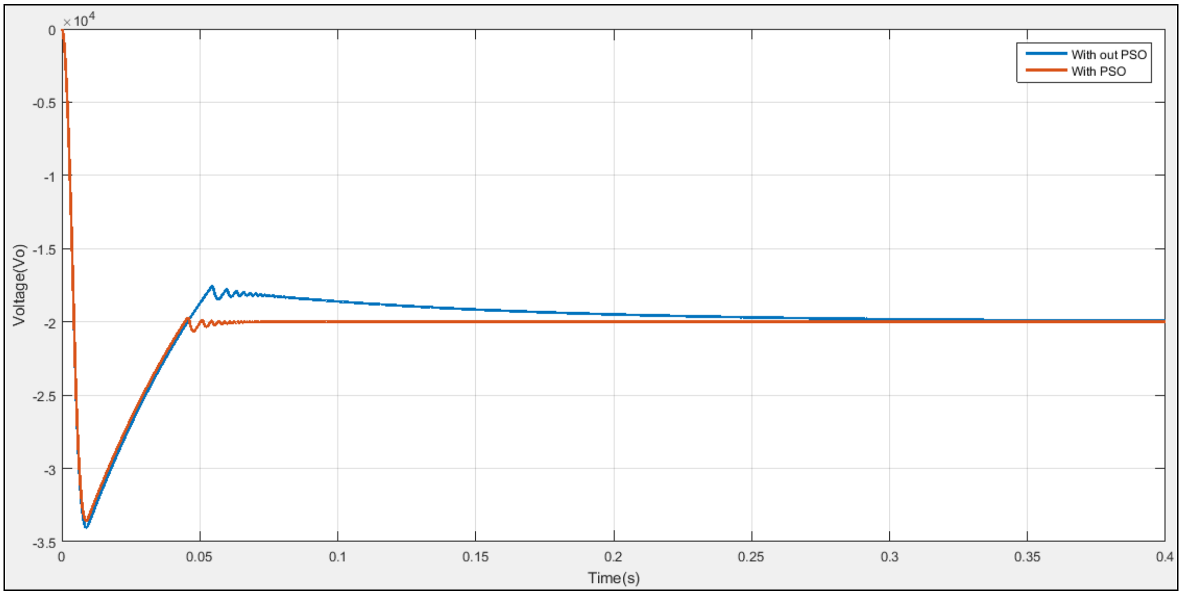


Fig 3: Output voltage of the LCC resonant converter

As can be seen, the output voltage of the LCC resonant converter is faster by using the particle swarm algorithm in transient response state. It can be seen that after passing the transient response, the voltage of the electrostatic precipitators system has reached a specified value, which is indicative of the correctness of the LCC resonance converter controller. In figure 4, the inverter output current of the simulated LCC resonant converter is shown. In figure 5 the extensive mode is presented.

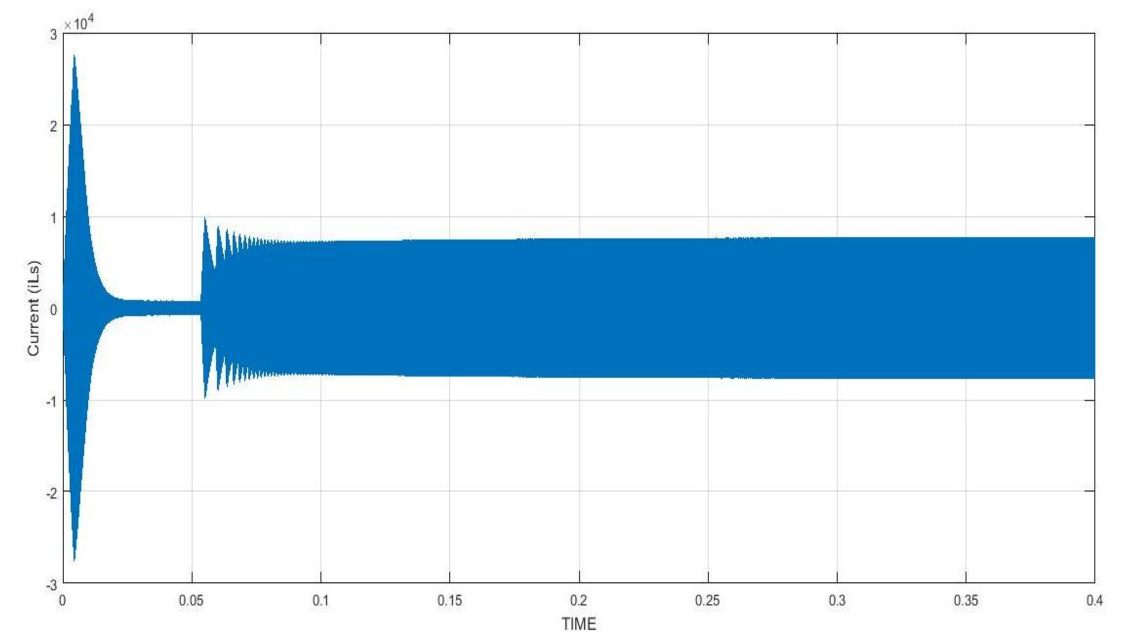


Fig 4: Output current of LCC resonant converter

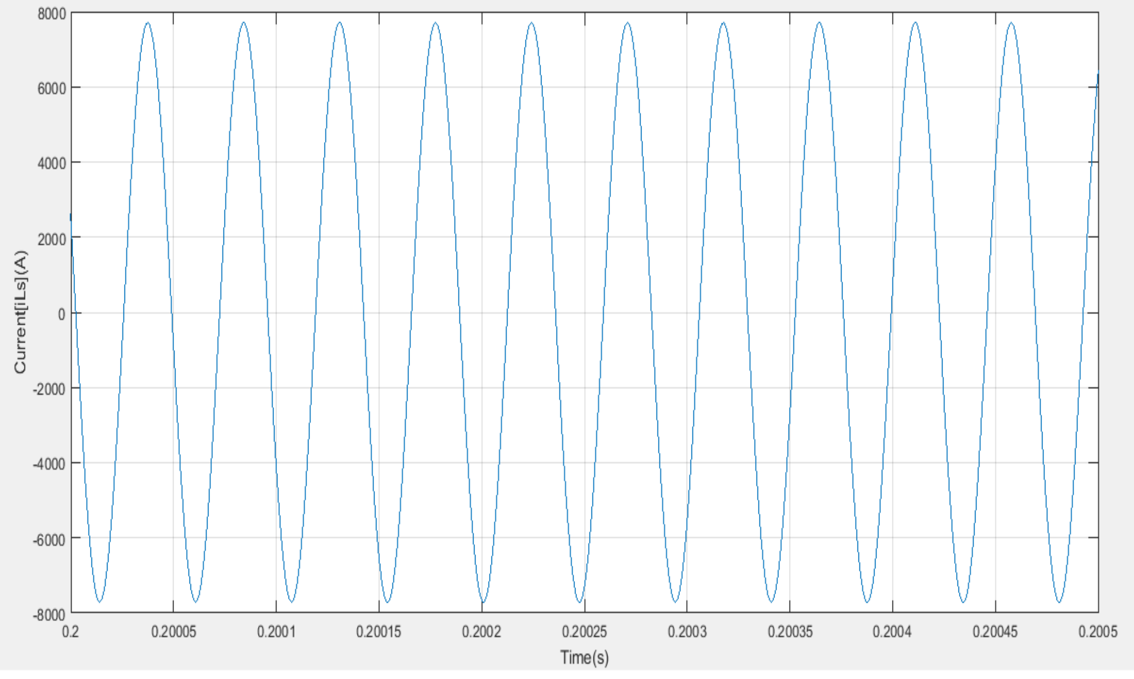


Fig 5: Extensive display of LCC resonant converter output

In figure 6, the cost function of the number of recalls, and in figure 7, the cost function of the frequency of repetitions for the particle swarm algorithm are shown. Also, the number of iteration algorithms is 40, which is considered for each population of 10. In the various researches, the cost function of recalls is used as an estimation of optimization algorithms, and less number of recalls can confirm the optimal solution in the search space and show algorithm is more suitable for solving the problem. Therefore, according to figure 6, it is concluded that the particle swarm algorithm performance is acceptable. In figure 7, the cost function is shown as the number of repetitions.

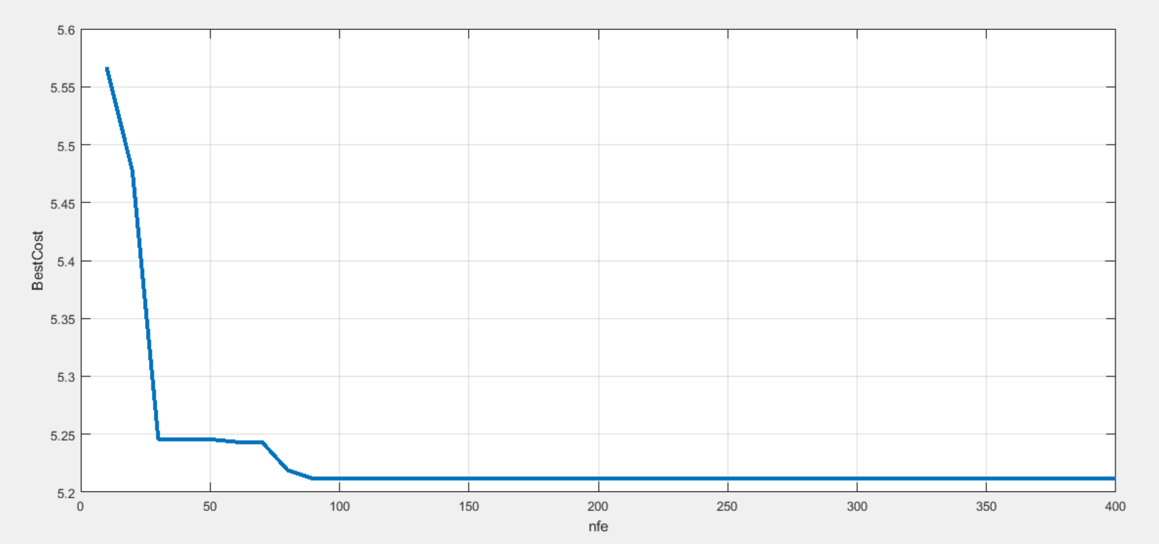


Fig 6: Cost function based on the number of recalls

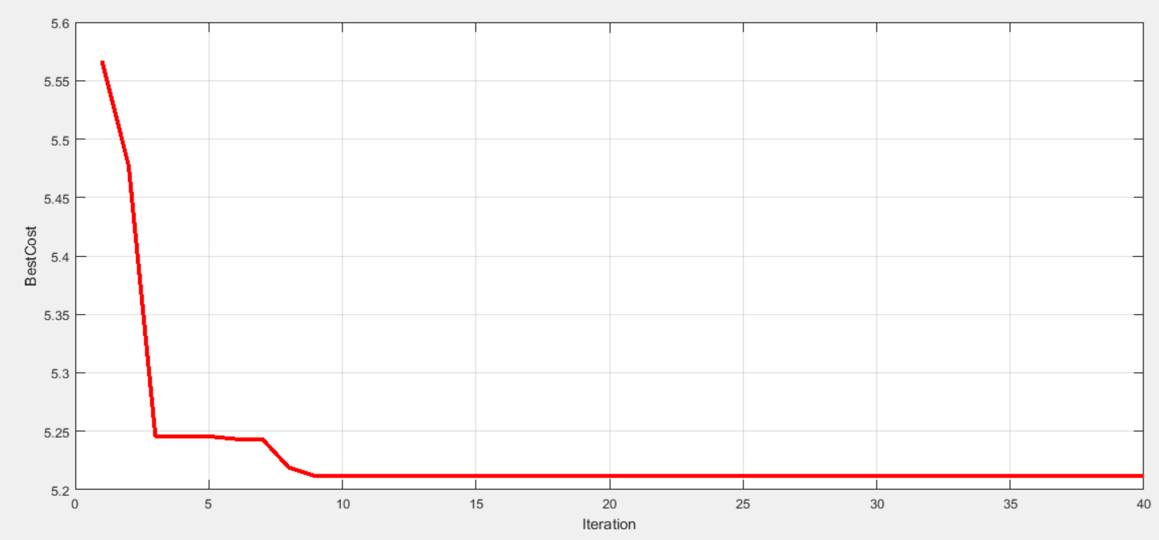


Fig 7: Cost function based on the number of iteration

4. Conclusions

Conventional frequency power supplies are still used for many applications, including electrostatic precipitator systems. In the high voltage power supply mode, the advantage of high frequency switching operation reduces the dimensions and weight of the equipment being installed. On the other hand, high-frequency switching results a low-voltage direct-current output with little ripple, which increases the efficiency of the filter. It also increases the efficiency and reduces voltage stress in the electrodes. Therefore, the use of high frequency resonance power supplies is recommended. To overcome that, using an evolutionary particle swarm algorithm, we set up a proper setting for optimizing the controller values. In this paper, due to the structure of the desired resonant converter and the dependency on the load and frequency, the design was carried out. The results of simulation show that the output response is particularly suitable.

5. References

1. McLean KJ. Electrostatic precipitators, in IEE Proceedings A - Physical Science, Measurement and Instrumentation, Management and Education - Reviews. 1988; 135(6):347-361.
2. Tschirhart DJ, Jain PK. A CLL resonant asymmetrical pulse width modulated converter with improved efficiency, IEEE Transactions on Industrial Electronics. 2008; 55(1):114-122.
3. Lam JCW, Jain PK. A modified valley fill electronic ballast having a current source resonant inverter with improved line-current total harmonic distortion (THD), high power factor, and low lamp crest factor, IEEE Transactions on Industrial Electronics. 2008; 55(3):1147-1159.
4. Barragan LA, Navarro D, Acero D, Urriza I, Burdio JM. FPGA implementation of a switching frequency modulation circuit for EMI reduction in resonant inverters for induction heating appliances, IEEE Transactions on Industrial Electronics. 2008; 55(1):11-20.
5. Feng W, Lee FC, Mattavelli P, Huang D, Prasantanakorn C. LLC resonant converter burst mode control with

constant burst time and optimal switching pattern, 26th Annual IEEE Applied Power Electronics Conference and Exposition (APEC). 2011, 6-12.

6. Feng W, Lee FC, Mattavelli P. Optimal trajectory control of burst mode for llc resonant converter, IEEE Transactions on Power Electronics. 2013; 28(1):457-466.
7. Vukosavic SN, Peric LS, Susic SD. A novel power converter topology for electrostatic precipitator, IEEE Transaction on Power Electronics. 2016; 31(1):152-164.
8. Soeiro T, Biela J, Muhlethaler J, Linner J, Ranstad P, Kolar JW. Optimal design of resonant converter for electrostatic precipitators, in Proc. IPEC, Sapporo, Japan. 2010, 2294-2301.
9. Maguiri OEl, Giri F, Dugard L, Fadil Hel, Chaoui FZ. Nonlinear adaptive output feedback control of series resonant dc-dc converters, IEEE Conference of American Control. 2010, 3287-3292.
10. Ranstad P, Nee HP. On dynamic effects influencing IGBT losses in soft-switching converters, IEEE Trans. Power Elect. 2011; 26(1):260-271.
11. Du Y, Wang J, Wang G. Modeling of the High-Frequency Rectifier With 10-kV SiC JBS Diodes in High-Voltage Series Resonant Type DC–DC Converters, IEEE Trans. Power Elect. 2014; 29(8):4288-4300.
12. Guo T, Zhang C, Chang L. Large-signal modeling of LCC resonant converter operating in discontinuous current mode applied to electrostatic precipitators, Applied Power Electronics Conference and Exposition (APEC), 2013 Twenty-Eighth Annual IEEE, 2013.
13. Soeiro T, Muhlethaler J, Linner J. Automated Design of a High-Power High-Frequency LCC Resonant Converter for Electrostatic Precipitators, IEEE Industrial Electronics Society. 2013; 60(11):4205-4819.
14. Ranstad P, Mauritzson C, Kirsten M, Ridgeway R. On experiences of the application of high-frequency power converters for ESP energization, in Proc. ICESP. 2004, 1-16.
15. Lin BR, Dong JY, Chen JJ. Analysis and implementation of a ZVS/ZCS DC-DC switching converter with voltage step-up, IEEE Trans.Ind. Electron. 2011; 58(7):2962-2971.
16. Wu X, Hua G, Zhang J, Qian Z. A new current-driven synchronous rectifier for series-parallel resonant (LLC) DC-DC converter, IEEE Trans. Ind. Electron. 2011; 58(1):289-297.
17. Mondal D, Chakrabarti A, Sengupta A. Optimal placement and parameter setting of SVC and TCSC using PSO to mitigate small signal stability problem, Electrical Power and Energy Systems. 2012; 42:334-340.
18. Kennedy J, Eberhart R. Particle swarm optimization. In Proceedings of IEEE international conference on neural networks. 1995; 4(2):1942-1948.
19. Zakariapour A, Derakhshan-B P. Sub-harmonics fluctuations cancellation in LED resonant-switching driver controller using imperialistic competitive algorithm. Int. J of Mult. Res. and Devel. 2018; 5(1):168-169.