WIRELESS POWER TRANSFER SYSTEM POWER FACTOR CORRECTION WITH PSO BASED SERIES-SERIES COMPENSATION

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***Abstract*—** This work describes the development of a new algorithm for the solution of a multi-objective problem in power systems with boost converter using Particle Swarm Optimization. Basically, the purpose is to search an optimal operation point of system which allows simultaneously power factor remote control and loss minimization. This paper introduces a PFC modulated WPT method which can realize PFC function through phase-shift modulation of the primary-side inverter of a series-series (SS) WPT system. A close-loop control method of the phase-shift modulated system is also proposed for practical implementations. Without using a PFC converter, the structure of a WPT system can be simplified. The principle proposed used to obtain the data from vulnerability analysis to characterize the power system, with no necessity of knowing the whole set of network parameters. A hybrid load flow using parameters of the series-series (SS) WPT system without the formal construction algorithm is presented. The optimization problem was solved by particle swarm optimization. The results obtained in the system demonstrated the efficiency of the proposed methods, once in all the simulations carried out for different operation conditions no convergent difficulties occurred using the hybrid load flow, and the power factor in the interconnection bus was kept close to the unit and have got advance in loss minimization acquired using de optimal load flow**.**

***Keywords*—** Particle Swarm Optimization**,** series-series (SS), Power factor control (PFC), Wireless Power Transfer (WPT), hybrid load flow.

1. INTRODUCTION

In recent years, energy and environmental problems have become increasingly serious, and the rise of electric vehicles (EVs) might be a solution to the pollution caused by the emissions of traditional fuel vehicles. As the scale of EVs continues to expand, it is urgent to solve the problems of insufficient supply of charging piles and unreasonable distribution of charging locations. Due to the emergence of high-power, high-switching frequency semiconductor devices, researches on WPT technology have been widely carried out. Compared with traditional wired charging systems, and the PSO algorithm WPT offers many benefits such as high electrical isolation, high flexibility and high reliability, especially in harsh environments. WPT has been widely adopted. Grid-connected power electronic converters need to limit the total harmonic distortion and have a high power factor. To reduce the grid reactive power and current harmonics, PFC converters are widely used in medium and high-power WPT systems. Active PFC circuits can be implemented using various converter topologies, including buck, boost, and fly back converters among these topologies, boost converters are currently widely adopted (Fig. 1).

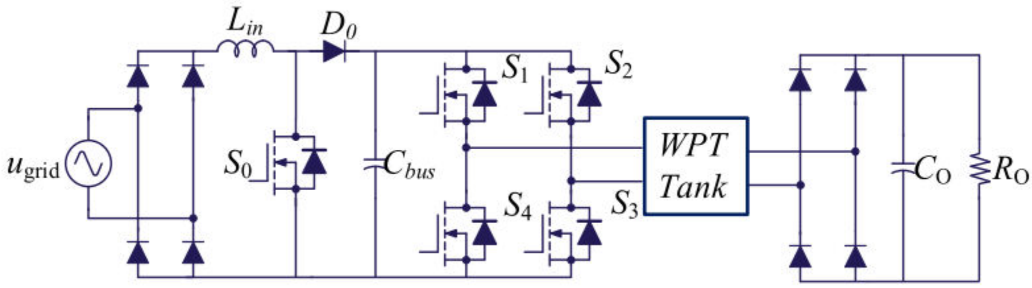


Fig 1 Traditional single-phase two-stage AC-DC WPT system with boost PFC.

According to the locations of the PFC converter, it can be divided into front-end PFC [17] and back-end PFC [18]. The classic front-end PFC is connected to the AC grid through a boost circuit to ensure high input power factor [19]. The front-end PFC converter of [20] consists of three parallel switches to reduce component stress and ensure safe operation of the circuit. The PFC converter is connected to the receiver in [21], and the topology is chosen so that the PFC stage has a sufficiently high input voltage with a weak coupling. The back-end PFC can simplify the structure of the primary side, but it will introduce pulsating power to the output.

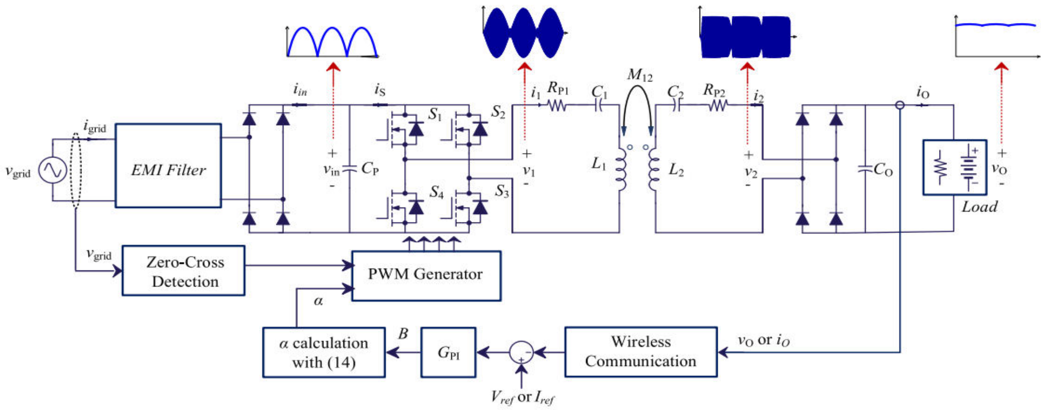


Fig.2. The WPT system with phase-shift PFC modulation.

Various approaches have been proposed to eliminate multiple stages in the transmitter of a WPT system. The commonly adopted technique is to use an AC-AC matrix converter to replace the traditional rectifier-PFC converter-inverter structure [23], [24]. Based on the series-parallel (SP) compensation topology, a three-phase AC-AC matrix converter comprising of six reverse-blocking switches and one regular switch, as long as a variable-frequency control strategy is proposed in [25] for WPT applications. PFC is realized by adopting the energy-injection and free-oscillation technique.

2. PROPOSED CONTROLLER PARTICLE SWARM OPTIMIZATION

In this tutorial, we'll understand how Particle Swarm Optimization (PSO) works. Mainly, we'll explore the origin and the inspiration behind the idea of PSO. Then, we'll detail the algorithm procedure. We'll start by defining its concept and continue by mathematically modeling its parameters.

Then, we'll continue by listing the sequence of the executing steps and representing the corresponding flowchart. Finally, we'll present domains of applications where PSO can be used to solve real-world problems. A finishing conclusion will summarize our tutorial.

3. Origin and Inspiration:

The diversity in nature and its systems has driven diversity in the emerging algorithms and techniques created by imitating how nature works. We can divide them into two groups. The first one uses inputs inspired by biological entities (cells or neurons) behavior such as neural networks, genetic algorithms, and evolutionary algorithms. The second one uses inputs inspired by biological systems' behavior, such as ants, lions, bees, etc. We call them Swarm Intelligence algorithms. In this tutorial, we'll study the PSO algorithm and how it works.

Particle Swarm Optimization is a meta-heuristic that belongs to the category of swarm intelligence algorithms.

It was first proposed by James Kennedy and Russell Eberhart in 1995 and is applied to various search and optimization problems. Let's start by defining the three keywords in the definition. What is an optimization problem? What is a meta-heuristic? And what is swarm intelligence?

We can simply define optimization by a commonly used concept that locates the optimum solution among a set of feasible solutions. It has a fundamental role in determining some variables with certain resource limits.

Meta-heuristics are high-level procedures that aren't dependent on the problem instance or example. We can say they are heuristics with more generalized rules than standard heuristics and can solve multiple mathematical problems.

As for swarm intelligence, we can define it as artificial intelligence that is based on the collective behavior of decentralized and self-organized systems. These systems typically comprise a population of individuals (agents) interacting locally and with their environments. The agents' cooperation creates a collective intelligence that demonstrates great results when applied in the computer networks field. We can find many popular swarm intelligence algorithms such as ant colonies, bird flocking, fish schooling, grey wolves, lions, whales, ant, etc.

4. Particle Swarm Optimization:

Let's look closely at the concept of work and the mathematical model of the PSO algorithm. Then, let's show its representative flowchart.

Concept- How It Works:

PSO is a population-based technique. It uses multiple particles that form the swarm. Each particle refers to a candidate solution. The set of candidate solutions co-exists and cooperates simultaneously. Each particle in the swarm flies in the search area, looking for the best solution to land. So, the search area is the set of possible solutions, and the group (swarm) of flying particles represents the changing solutions.

Throughout the generations (iterations), each particle keeps track of its personal best solution (optimum), as well as the best solution (optimum) in the swarm. Then, it modifies two parameters, the flying speed (velocity) and the position. Specifically, each particle dynamically adjusts its flying speed in response to its own flying experience and that of its neighbors. Similarly, it tries to change its position using the information of its current position, velocity, the distance between the current position and personal optimum, and the current position and swarm optimum.

The swarm of particles (birds) continues moving toward a promising area until getting the global optimum, which will solve the optimization problem. Following, we'll define the mathematical models, illustrated by the used parameters and the equations, to build the PSO algorithm.

Parameters:

The main parameters used to model the PSO are:

- a swarm of particles
- an individual in the swarm with a position and velocity ,
- the position of a particle
- the velocity of a particle
- the best solution of a particle
- the best solution of the swarm (Global)
- fitness function
- acceleration constants (cognitive and social parameters)
- random numbers between 0 and 1
- the iteration number

5. Mathematical Models:

Two main equations are involved in the PSO algorithm. The first (equation 1) is the velocity equation, where each particle in the swarm updates its velocity using the computed values of the individual and global best solutions and its current position. The coefficients of and are acceleration factors related to the individual and social aspects.

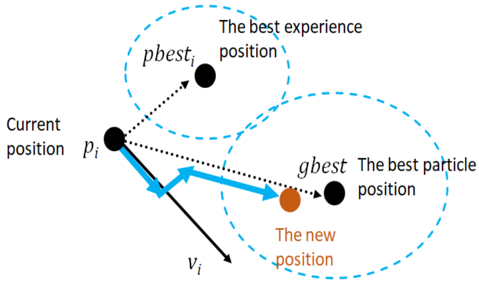
They are known as trust parameters, with modeling how much confidence a particle has in itself and modeling how much confidence a particle has in its neighbors. Together with the random numbers and, they define the stochastic effect of cognitive and social behaviors:

$$v_i^{t+1} = \underbrace{v_i^t}_{\text{Inertia}} + \underbrace{c_1 r_1 (pbest_i^t - p_i^t)}_{\text{Personal influence}} + \underbrace{c_2 r_2 (gbest^t - p_i^t)}_{\text{Social influence}}$$

The second (equation 2) is the position equation, where each particle updates its position using the newly calculated velocity:

$$p_i^{t+1} = p_i^t + v_i^{t+1}$$

The parameters of position and velocity are co-dependent, i.e., the velocity depends on the position and vice-versa. We can illustrate the moving particle in the following figure:



6. Steps and Flowchart:

After explaining the PSO principle and its mathematical model, let's examine the PSO execution steps:

1. Initialize algorithm constants.
2. Initialize the solution from the solution space (initial values for position and velocity).
3. Evaluate the fitness of each particle.
4. Update individual and global bests.
5. Update the velocity and position of each particle.
6. Go to step 3 and repeat until the termination condition.

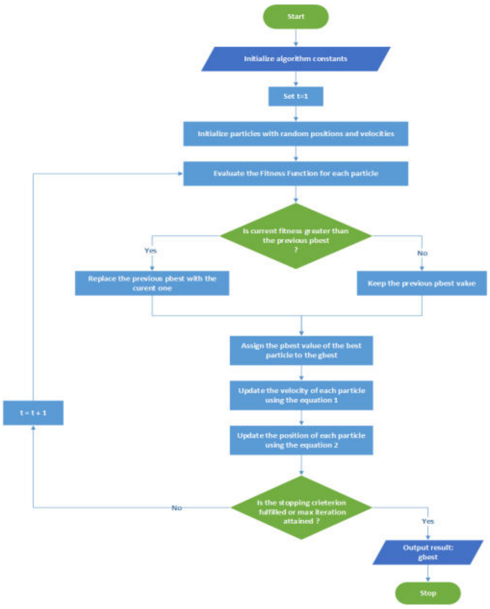


Fig 3. The flowchart detailing and organizing the execution steps can help us understand the PSO method:

PSO Applications:

PSO is known to be advantageous in many aspects. First, it is simple to implement. Second, it is derivative-free and uses very few parameters. Third, it has an efficient global search process. That is why we can say that it has been a popular technique exploited to solve several optimization problems. Let's dig into some examples:

1. The training of neural networks which is used to identify Parkinson's disease, extract rules from fuzzy networks, or recognize images
2. The optimization of electric power distribution networks
3. Structural optimization, where the construction industry targets the optimal shape, size, and topology during the design process
4. System identification in biomechanics

7. GRID-CONNECTED POWER ELECTRONIC CONVERTERS

Grid-connected power electronic converters need to limit the total harmonic distortion and have a high power factor. To reduce the grid reactive power and current harmonics, PFC converters are widely used in medium and high-power WPT systems. Active PFC circuits can be implemented using various converter topologies, including buck, boost, and flyback converters [16].

Various approaches have been proposed to eliminate multiple stages in the transmitter of a WPT system. PFC is realized by adopting the energy-injection and free-oscillation technique. A single-phase AC-AC matrix converter as well as an active rectifier are adopted in [26] to realize bidirectional WPT, based on dual-LCC compensation. The condition of realizing PFC have been derived and the modulation of secondary-side active rectifier is practically implemented. In [28], frequency modulation is proposed for PFC with a rectifier-inverter and SP compensation topology. In [29], a single-stage PSO based WPT resonant converter with front-end bridgeless boost PFC rectifier is proposed. The bridgeless boost PFC converter is combined with the inverter so that less switches are required. However, the voltage usage rage of this converter is low and thereby it which performs AC-DC PFC rectification and DC-DC WPT conversion simultaneously to generate AC power containing. Nowadays, several numerical techniques, within the metaheuristics, propose solutions for optimal load flow problems with divers objective.

Approach the Particle Swarm Optimization to determine the loading point maximum, affixing voltage stability margins. This tool seems to become an important alternative for optimal load flow solution. This work describes the development of a new algorithm based on vulnerability analysis for solution of a multi-objective problem in power systems with wind produces connected using Particle Swarm Optimization.

8. PFC WITH PHASE-SHIFT MODULATION:

A. MODULATION SCHEME:

Phase-shift modulation is widely adopted to regulate the output voltage of a full-bridge inverter by changing the relative phase angle between two inverter legs. Firstly, also because CP is a small capacitor which has negligible effect on the line-frequency voltage after rectification, the amplitude of the DC input voltage of the inverter is assumed the rectified grid voltage. In a switching cycle, the input voltage of the inverter can be considered constant. Therefore, the RMS value of the fundamental component of the inverter output voltage in a switching cycle

B.COUPLER DESIGN

The coupler design process of the phase-shift modulation system is provided in this section. To maximize the usage rate of the input voltage of the inverter, B is set to 1 when designing the coupler. Firstly, the winding currents should be determined so that the number of strands of the wires can be determined. The primary winding current is calculated with (12) after the output voltage of the application is given. Similarly, the RMS value of the secondary winding current in the time scale of the inverter switching cycle.

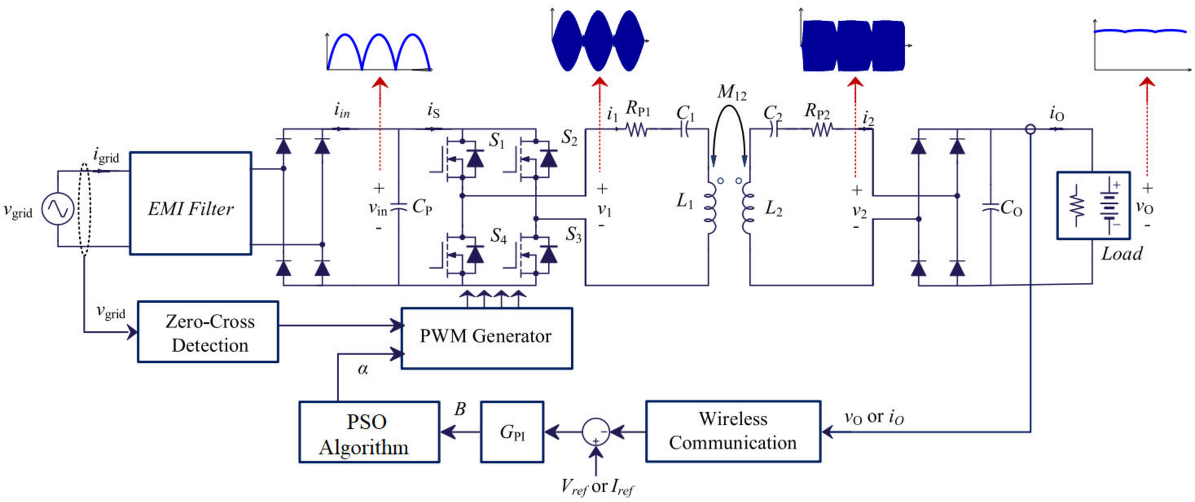


Fig.4 Proposed WPT system with phase-shift PFC modulation with PSO Algorithm.

9. OPTIMAL POWER FACTOR CALCULATION

- The particle swarm optimization PSO was supported in the optimal power factor correction. Thus, the algorithm of the process of optimal load flow calculation to dispatch power factor of AC system
- Construction of the Zbus from the data of the vulnerability study.
- Start the iterative process.
- Actualization of the active and reactive power in the feeder buses of the distribution company by particle swarm optimization.
- Actualization of the bus voltages according to the Zbus Load Flow.
- Actualization of the active and power factor in the interconnection bus accomplishing an iteration of the Power Summation Load Flow.
- Actualization of the power factor dispatch on wind farm by PSO.

Particle Swarm Optimization.

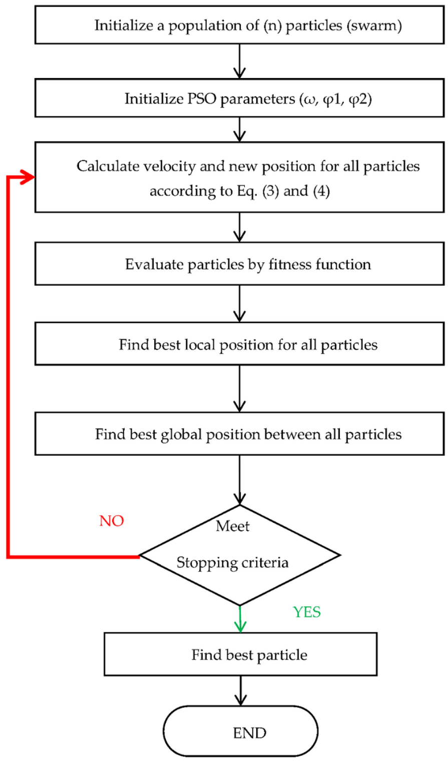


Fig5. PSO Algorithm Flow chart

- Particle Swarm Optimization or PSO is a metaheuristic developed based on social behaviors of animals like birds and fishes [17].
- Like this, it is a method based on population of solutions.
- In PSO to each potential solution one speed is attributed, in that way, the potential solutions, denominated particles, making possible the movement for the search space,
- Each particle conserves the information of the best individual value (pbest - local) and of the whole swarm (gbest - global) based on the object function.
- In each iteration of PSO, the particles speed towards the position defined by pbest and gbest is increased.
- The acceleration of this search is taken into account by using a randomly generated term, in order to combine the positions information at pbest and gbest, aiming to determine the current speed.
- Particle Swarm Optimization that proposes the inclusion of Evolutionary Algorithms in the traditional algorithm to improve the efficiency of the convergence.

10. RESULTS

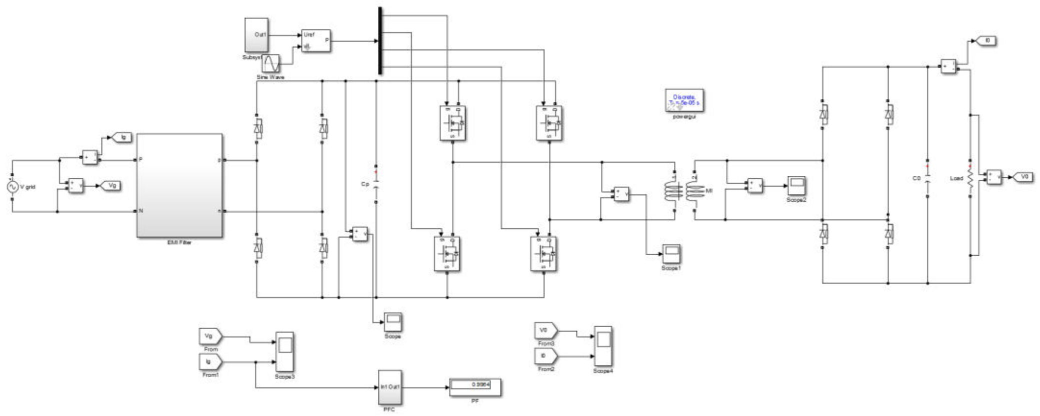


Fig 6. Simulation Diagram of the proposed system

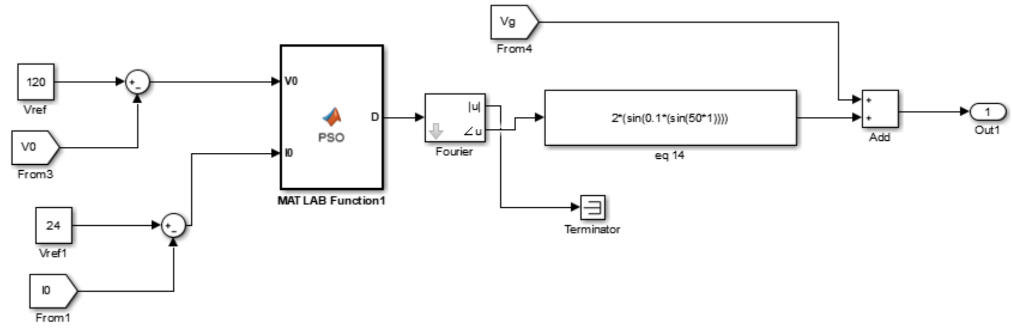


Fig 7. Proposed Controller Diagram

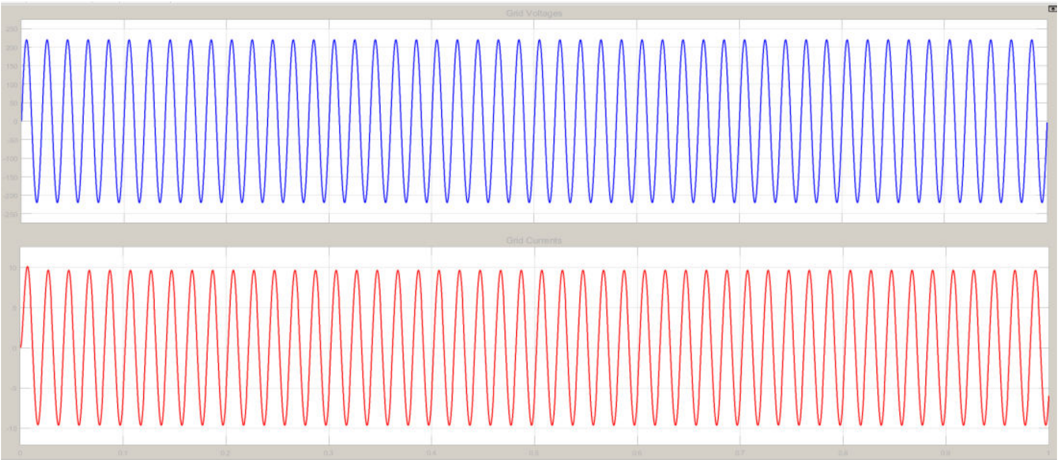


Fig 8. Grid Voltage and Current

Grid Voltage and Current with the Power Factor of 0.9964 which was shown below with the PSO algorithm

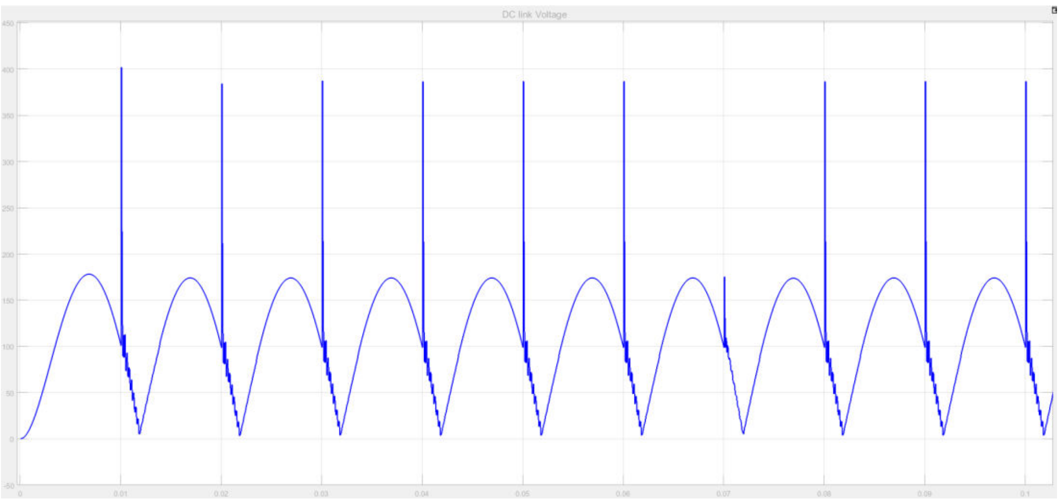


Fig 9. DC link Voltage after the Rectification without filter

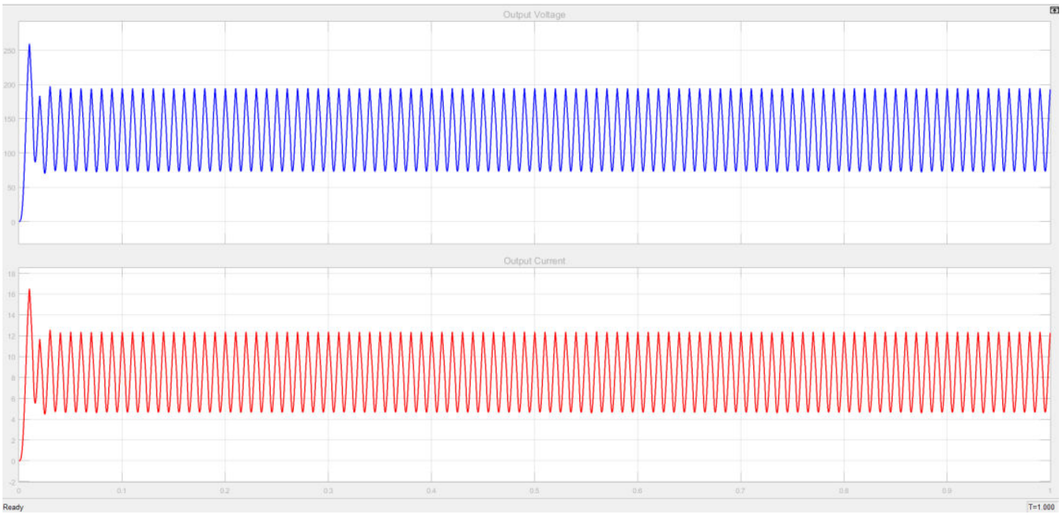


Fig 10. Output Voltage and Currents of the Nonlinear load.

CONCLUSION

This paper proposes a PFC-modulated WPT system that realizes PFC function through the PSO-based phase-shift modulation of the primary-side inverter of the WPT system. Thereby, no PFC converter is required. The required phase-shift angle of the inverter is calculated. Close loop control for the PSO-based phase-shift PFC modulation is introduced. The gradient method, PSO showed to be an excellent alternative to model the optimal PFC, once in all simulations the program reached the convergence in a fast way. Another advantage of those methods is their easy implementation. According to the obtained results, the proposed algorithms showed to be adequate to implement the optimization of the presented objective function.

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