Türk Mühendislik Araştırma ve Eğitimi Dergisi
Turkish Journal of Engineering Research and Education

2(1), 1-8, (2023)

RESEARCH ARTICLE

Controlling Output Voltage and Correcting Power Factor Using Fractional PI Controller with Average Current Method in Wireless Energy Transfer

Kablosuz Enerji Transferinde Ortalama Akım Yöntemi ile Kesirli PI Kontrolör Kullanılarak Çıkış Gerilimin Kontrolü ve Güç Katsayısının Düzeltilmesi

Farhad Ahmad[1,*] Metin Demirtaş[1]
[1] Balikesir University, Electrical and Electronics Engineering Department, Balikesir, Turkey

Received / Geliş: 25.10.2022
Accepted / Kabul: 16.12.2022
***Corresponding Author: Farhad Ahmad, engrfarhan27@outlook.com**

ABSTRACT: Single-phase AC/DC converters with Power Factor Correction (PFC) circuit are used as full-wave controlled rectifiers in many power electronics circuits to provide high standards of efficiency and improve power quality. In parallel with the changes in the circuit topologies used, new algorithms are being developed in control methods. In recent years, new control and modeling methods using fractional derivatives and integrals have been developed. In this study, it is aimed to correct the power factor on AC side of the circuit and to keep the output voltage constant at the desired value by using a boost converter for wireless energy transfer. Fractional order PI (FOPI) controller is used to control output voltage and a classical PI controller is used to generate a reference current of boost converter. The Particle Swarm Optimization method was used to optimize the controller coefficients. As a result of the simulation studies, the power coefficient was kept at 0.99.

Keywords: Wireless power transfer, power factor correction, AC-DC converter, boost converter

ÖZ: Güç Faktörü Düzeltme (PFC) devreli tek fazlı AC/DC dönüştürücüler yüksek standartlarda verim sağlamak ve güç kalitesini iyileştirmek amacıyla birçok güç elektroniği devresinde tam dalga kontrollü doğrultucu olarak kullanılmaktadır. Kullanılan devre topolojilerindeki değişikliklere paralel olarak kontrol yöntemlerinde de yeni algoritmalar geliştirilmektedir. Son yıllarda kesirli türev ve integralin kullanıldığı yeni kontrol ve modelleme yöntemleri geliştirilmektedir. Yapılan çalışmada kablosuz enerji transferinde yükseltici dönüştürücü kullanılarak devrenin AC tarafında güç katsayısının düzeltilmesi ve çıkış geriliminin istenen değerde sabit tutulması amaçlanmaktadır. Çıkış gerilimini kontrol için Kesirli PI kontrolör ve yükseltici dönüştürücünün referans akımını üretmek için ise klasik PI kontrolör kullanmıştır. Kontrolör katsayılarının optimize edilmesi için Parçacık Sürü Optimizasyon yöntemi kullanılmıştır. Benzetim çalışmaları sonucu güç katsayısı 0.99 değerinde tutulmuştur.

Anahtar Kelimeler: Kablosuz enerji aktarma, güç faktörü düzeltme, AC-DC dönüştürücü, yükseltici dönüştürücü

1. INTRODUCTION

Power electronics users are increasing day by day [1] with the invention of new control techniques and invention of renewable energy resources, power converters are getting highly important. In power appliances, AC-DC converters are very important [2]. Modeling of controllers is done by average signal and linearization methods [3]. They also have numerous applications in the domain of PFC. Power Factor (PF) is decreased by the effect of harmonics and switching. This is detected by the waveform of the circuit. So, the grid is polluted by

Farhad Ahmad, Orcid: 0000-0002-1338-4328 / Metin Demirtaş, Orcid: 0000-0003-2622-5286

current harmonics, which affects the power quality of grid. According to the IEC 61000-3-2 and the IEEE /ANSI 519 international standards, correction of power factor and current harmonics range are determined, simultaneously [4]. To transfer the maximum power, PF should be unity [5].

A general review of PFC in single-phase AC/DC converters using the boost converter topology for low and medium voltage as well as power appliances is discussed in reference [6]. Here PI controller is used to adjust the output voltage in DC-DC cascade boost converter [7]. In an induction heating system, PID controllers are designed and analyzed in such a way as to remove the harmonics and adjust the PF near unity [8]. An active snubber cell (ASC) with a PFC boost converter is presented to charge the batteries discussed in [9]. Conditions of soft switching and unity PF gained from light load to full load conditions in discussed here [10]. A wind turbine-based bat algorithm using hybrid fractional fuzzy PID to control the MPPT pitch is discussed in [11].

Leibnitz and L′ Hospital introduced the fractional calculus theory in the late 1600s. Many studies have been done in this area. The idea of fractional calculus for feedback control was explained in 1940. It is also noticeable that classical PID controller has not better performance than FOPID controllers [12]. The fractional PI controller to correct the power factor for variable loads is briefly explained in [13].

In 1891, Nikola Tesla had done the first experiment on wireless power transfer. At the resonance frequency, wireless power transfer (WPT) by using magnetic coupling is discussed in the conference paper [14]. Wireless Charging (WC) has numerous benefits over wired charging methods. In the WPT system, the source has no physical connection with a load. Therefore, there is not any sparking chance in the system [15]. It is friendly to the environment [16]. To transfer the energy using the magnetic field, an inductively coupled power transfer (ICPT) system is used. ICPT system has minimum of two coils (primary and secondary coils). Both coils are magnetically coupled to each other. ICPT transfers energy using these inductors by the change of current [17]. The efficiency of the circuit for WPT using the Series-parallel (SP) model is discussed in [18]. FOPI for WPT with high efficiency is discussed in [19].

In this research, controlling output voltage and PFC using a FOPI controller with an Average Current Control Method for WPT are described briefly. To determine the optimal parameters of controllers, Particle Swarm Optimization (PSO) algorithm is used. Simulation has been completed using MATLAB/Simulink R2017B. The designed circuit consists of an AC-DC converter containing a transformer, boost converter and WPT system. The phase difference between current and voltage at the source side should be minimum to maintain the stable required voltage and power factor near unity. The input current waveform should be sinusoidal and output voltage should be regulated to the desired reference value [20]. To sense the current in the main circuit, R_s resistor is used [21]. The value of resistor is very small because it consumes power. Therefore, its value is carefully chosen as 0.02 Ω [22]. A Fourier block of Matlab/Simulink software is used to detect the PF of circuit.

The paper concerned as like: Section 1 describes the introduction and section 2 describes wireless power transfer. Section 3 describes designing and calculation of coil. Section 4 describes the fractional order PI controller, section 5 describes the simulation and power correction, section 6 prescribes the conclusions, section 7 prescribes the acknowledgment and section 8 describes references.

2. WIRELESS POWER TRANSFER

Power electronic engineers motivated by the revolution in wireless charging batteries for Electric vehicles (EVs). Therefore, many scientists are researching nowadays to overcome wireless charging problems [23]. Charging of batteries using wireless technology is more reliable because it eliminates the necessity of a plug for an electricity outlet [24].

In the literature, there are two different theories which can be used for the analysis of WPTs. These theories are Coupled Mode Theory and Equivalent Circuit Theory (ECT). In this research, ECT is discussed only. There are four basic WPT systems. These systems are series–series (SS), series-parallel

(SP), parallel–series (PS), parallel – parallel (PP). In this paper, only the SS equivalents circuit is discussed and its diagram is given in Figure 1. The main goal of this paper is to transfer the energy using magnetic resonance by means of the air medium [25].

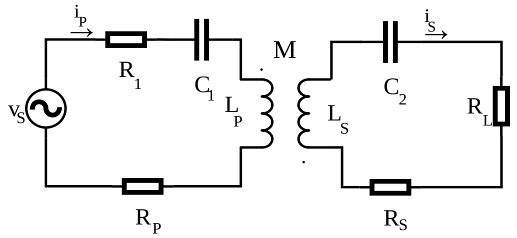

Figure 1: SS model of WPT.

Here V_s is the high-frequency voltage at the primary coil of WPT system. C_1 and C_2 are the series capacitors for primary and secondary coils respectively. R_1 is the internal resistance at high frequency. R_L is the load. R_P and R_S are the parasitic resistances for primary and secondary coils. Using Kirchhoff's voltage law in Figure 1, equation (1) and equation (2) can be written as below.

$$v_S = (R_1 + R_P + j\omega L_P + \frac{1}{j\omega C_1})i_p + j\omega M\, i_S \tag{1}$$

$$0 = (R_L + R_S + j\omega L_S + \frac{1}{j\omega C_2})i_S + j\omega M\, i_P \tag{2}$$

Here M is the mutual inductance of coils, i_P and i_S are the current flowing from the primary and secondary loop of Fig. 1. So, the impedance equations for primary Z_1 and secondary coils Z_2 are written in equation (3) and equation (4), as mentioned below.

$$Z_1 = R_1 + R_P + j\omega L_P + \frac{1}{j\omega C_1} \tag{3}$$

$$Z_2 = R_L + R_S + j\omega L_S + \frac{1}{j\omega C_2} \tag{4}$$

Putting the values of equations (3) and (4) into equations (1) and (4), respectively. The obtained results are written below.

$$v_S = Z_1 i_P + j\omega M i_S \tag{5}$$

$$0 = Z_2 i_S + j\omega M i_P \tag{6}$$

i_P and i_S can be written as below by re-arranging the equation (5) and (6)

$$i_P = \frac{Z_2 v_S}{Z_1 Z_2 + (\omega M)^2} \tag{7}$$

$$i_S = -\frac{j\omega M v_S}{Z_1 Z_2 + (\omega M)^2} \tag{8}$$

Equation (7) and equation (8) were used to calculate the input power and output power of the wireless system, respectively. The obtained input power and output power equations are written in equations (9) and (10).

$$P_P = \frac{Z_2 |v_S|^2}{Z_1 Z_2 + (\omega M)^2} \tag{9}$$

$$P_S = \frac{R_L |v_S|^2 (\omega M)^2}{\left[Z_1 Z_2 + (\omega M)^2\right]^2} \tag{10}$$

The efficiency of discussed circuit is determined from the ratio of equation (10) and equation (9). They are multiplied by 100. So, WPT system efficiency equation is written below.

$$\eta = \frac{R_L (\omega M)^2}{Z_2 \left[Z_1 Z_2 + (\omega M)^2\right]} \times 100\% \tag{11}$$

Therefore, it is clear from equation (11) that the input power, output power and efficiency are affected by the impedances of primary and secondary coil of the WPT system. To calculate the minimum equivalent impedance of the discussed circuit, the circuit should be operated on resonance conditions. The maximum current is flowing through the coils at resonance state. Equations (12) and (13) are written for primary and secondary circuit equations of the WPT system as below.

$$j\omega L_P + \frac{1}{j\omega C_1} = 0 \tag{12}$$

$$j\omega L_S + \frac{1}{j\omega C_2} = 0 \tag{13}$$

Using equation (6) and equation (7) with the equations (12) and (13), the output power equation is written as below.

$$P_R = \frac{R_L |v_S|^2 (\omega M)^2}{\left[(R_1 + R_P)(R_L + R_S) + (\omega M)^2\right]^2} \tag{14}$$

So, the efficiency equation of WPT system is written in equation (15).

$$\eta = \frac{R_L (\omega M)^2}{\left[(R_1 + R_P)(R_L + R_S) + (\omega M)^2\right]^2} \times \frac{1}{(R_L + R_S)} \times 100\% \tag{15}$$

3. DESIGNING AND CALCULATION OF WİRELESS COIL

In Figure 2, a simple model of wireless energy system is shown. These coils are pure copper and symmetrical. There are 25 turns in both coils. The radius of coil is 3.8 cm and radius of the wire is 1.5 mm. Primary and secondary coils have the same parameters. This model is designed on the ANSYS Maxwell. The distance between the two coils is 10 cm. There is no electrical connection between the coils, but the coils affect each other magnetically.

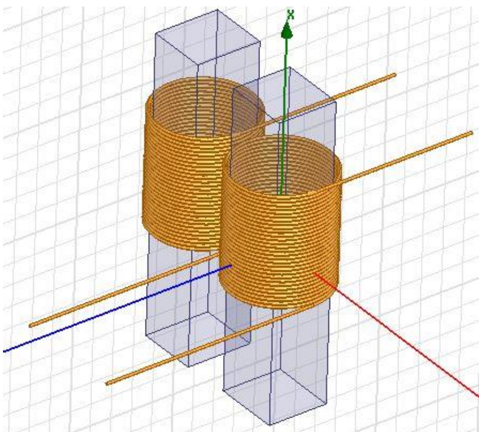

Figure 2: Designing of wireless coil.

The coils are chosen as symmetrical for ease of design. So equation (16) is used for primary and secondary coils to mathematically calculate the inductances of these coils.

$$L = N^2 C \mu_0 \mu_r \left[\ln\left(\frac{8C}{r}\right) - 2\right] \tag{16}$$

Here N is primary and secondary coil turns, C is the radius of a circular coil (m), r is the geometric mean radius of wire (m), μ_o is absolute permeability, ($\boldsymbol{4\pi} \times \mathbf{10}$-7 H/m) and μ_r is relative permeability.

The resonance frequency of WPT system for the primary and secondary sides can be premeditated by equations (17) and (18).

$$f_P = \frac{1}{2\pi\sqrt{L_P C_1}} \tag{17}$$

$$f_S = \frac{1}{2\pi\sqrt{L_S C_2}} \tag{18}$$

Here f_P and f_S are frequencies of the primary and secondary sides of the WPT system of designed circuit. Mutual inductance (M) between coils is calculated by using equation (19). K is the coupling factor. Its value range is between 0≤K≤1. Here K is selected as 0.2 for 10 cm distance.

$$K = \frac{M}{\sqrt{L_P L_S}} \tag{19}$$

To calculate the resistance of copper coil at a specified length, equation (20) is used. In mutual inductor Simulink block, the values of coil resistances are necessary to calculate using the below equation.

$$R = \rho \frac{L}{A} \tag{20}$$

Where R is resistance of the coil (Ω), $\boldsymbol{\rho}$ is resistivity of coil material, L is length of coil (m) and A is the cross-section of the circular coil (m^2).

The value of R_m is the sum of resistance of primary and secondary coil. It is compulsory to write in mutual inductor block of Simulink.

4. FRACTIONAL ORDER PI CONTROLLER

Classical integer order calculus is the general form of fractional calculus. It consists of integral differential operators of fractional orders. To find optimum values of the parameters of FOPI controller, different techniques are used. One of the tuning rules of FOPI controller is Particle Swarm Optimization (PSO) [12]. The mathematical expression derived by Grünwald-Letnikov is defined [26]-[27].

$$ {}_{c}D_{t}^{\alpha} f(t) = \lim_{h \to 0} \frac{\sum_{k=1}^{\left[\frac{t-c}{h}\right]} (-1)^{k} \binom{\alpha}{k} f(t-kh)}{h^{\alpha}} \tag{21} $$

The continuous fractional integral differential operator is written as follows [28]:

$$ {}_{\alpha}D_{t}^{r} = \begin{cases} \frac{d^{r}}{dt^{r}} & : r > 0 \\ 1 & : r = 0 \\ \int_{\alpha}^{t} (dt)^{r} & : r < 0 \end{cases} \tag{22} $$

The fractional order derivative, which is defined by Podlubny, can be given as below.

$$ \int_{0}^{\infty} D^{\alpha} y(t) e^{-st} dt = s^{\alpha} Y(s) - \sum_{k=0}^{N} s^{\alpha-k-1} y^{k}(0) \tag{23} $$

D^{α} y(t) is the derivative of order α of the function. α is a positive real number and $0 < \alpha < 1$. This method is used to determine the transfer function of FOPI. It is described below [28]-[29]:

$$ G_{c}(S) = k_{p} + k_{I} s^{-\lambda} \tag{24} $$

Here K_P is representing the Proportional coefficient and K_I is representing the Integral coefficient of FOPI controller. PSO algorithm is a stochastic optimization method and simulates the social behavior of animals such as foraging insects, birds and fish searching for food [30]. To find the optimal coefficients of the controller, PSO algorithm is used.

5. SIMULATION AND POWER FACTOR CORRECTION

The simulation of designed circuit diagram is shown in Figure 3. In this circuit, FOPI and PI controllers are used to regulate the output voltage and to generate the reference current. Firstly, AC supply voltage is converted into DC voltage using the AC-DC converter (bridge rectifier). Then using a boost converter, the obtained DC voltage is converted into high-voltage DC. To transfer this voltage using the WPT system, a DC-AC converter is used and the energy is transferred from the primary coil to the secondary coil. Then these voltages are again converted into DC voltage using a full bridge rectifier. The circuit consists of two controllers: 1) PI controller is inner loop controller and 2) FOPI controller is the outer loop controller. The inner controller is identified as the current controller which controls the input current of the circuit. Outer loop controller is also known as a voltage controller which regulates the output voltage. The output voltage of circuit is compared with the reference voltage and this signal goes to voltage controller. The voltage controller generates a signal which is sent to the multiplier block. It multiplies the rectified voltage and inverse square of peak voltage of source $V_s{}^2$ peak [5]. Then the signal goes towards the current controller after subtracting from the current of circuit. After that PWM generator block leads this signal to a gate of MOSFET. The frequency of PWM generator is selected as 85 kHz. A shunt resistance (0.02 Ω) is used to measure current flowing from the circuit. In this study, a boost converter is used for PFC. PF is measured at the source site. A Fourier block of MATLAB/Simulink is used at the input current signal to determine the PF. According to international standards, PF should be between 0.90-0.99 or near unity. The measured PF is 0.9992 or near unity. The parameters of designed circuit are shown in Table 1 and the optimized values of parameters are shown in Table 2.

Table 1: Parameters of the designed circuit.

Parameters	Values
L	34.1 μH
C_{out}	7 mF
R_L	53 Ω
V_{in}	230 V_{rms}
Supply frequency	50 Hz
R_s	0.02 Ω
Switching frequency	85 kHz
Rectifier capacitor	30 μF
L_P, L_S	98.83 μH
V_{ref}	350 V
Inductor of filter	693.2 μH

Table 2: Optimized values of controllers.

Selected controller	Inner controller	Outer controller
PI controller	k_P =0.01 k_I =0.1	-
FOPI controller	-	k_P =9.2929 k_I =8.7043 λ =0.7806

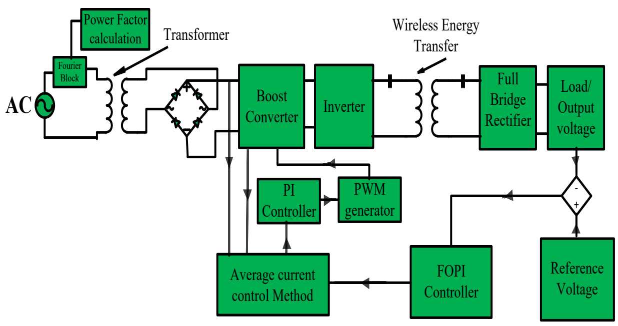

Figure 3: Matlab/Simulink block diagram.

The reference output voltage of designed circuit is selected as 350 V. The simulation output voltages are shown in Figure 4. It can be seen that there is a minor overshoot (0.001 V) occurred at almost 0.04s and a minor oscillation of output voltage can be neglected. So, it is clear that the desired output voltage is obtained successfully.

It is clearly shown that the output voltage is accurately obtained at the output of the circuit using the FOPI controller. The output current is shown in Figure 5. The output current is also smooth. In Figure 6, it is clearly shown that the power factor of designed circuit is 0.99 which is an ideal requirement of any circuit. To calculate the parameter coefficients of the FOPI controller and PI controller, the PSO Algorithm and ITAE function is selected to complete this process as described in [30].

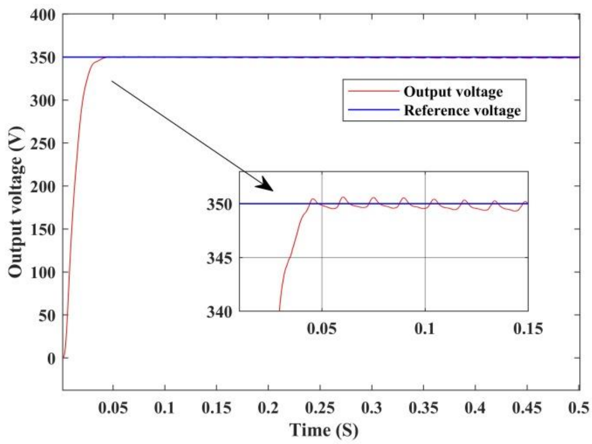

Figure 4: Output voltage using FOPI controller.

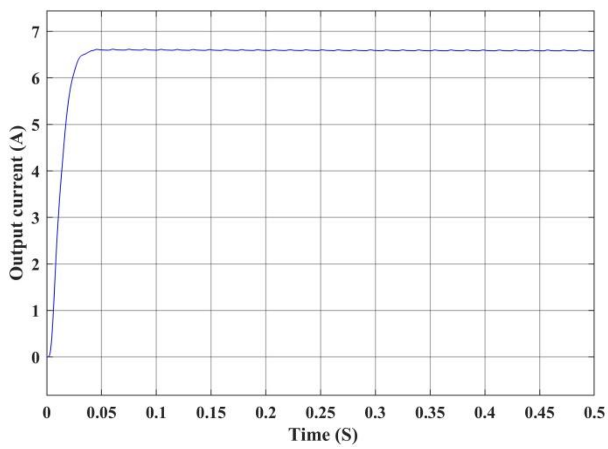

Figure 5: Output current using FOPI controller.

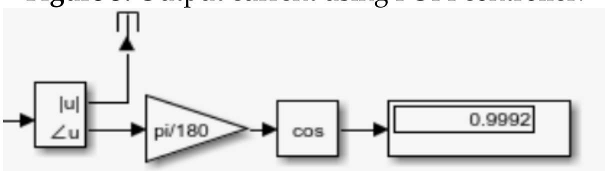

Figure 6: Power factor measurement using the Fourier block of MATLAB/Simulink.

6. CONCLUSION

This paper represents the controlling of output voltage and correcting power factor using the fractional PI controller and the average current method for a wireless energy transfer system. In the designed circuit, FOPI and PI controllers are used to correct the power factor and to transfer the maximum energy from source to load using

MATLAB/Simulation software. Here a simple boost converter topology is used to correct the PF because it is mostly used for this purpose and to increase the output voltage. Wireless energy transfer of series-series resonance circuit is also explained briefly. The controller coefficients are optimized by using PSO. The contribution of this paper to the literature is to design a circuit consisting of two controllers to provide quality energy for various loads like electrical vehicles. The output voltage is almost stable and achieved perfectly according to the selected reference voltage and the obtained value of power factor for the designed circuit is 0.99. This is a good result according to the international standard.

Author Contributions: Farhan Ahmed calculate and simulate the designed circuit under the supervision of Prof. Dr. Metin Demirtas. They prepared the paper with together. Contribution rate of Farhan is 60% and Metin is 40%

Acknowledgement: This study is supported by the BAP project 2022/012 Balikesir University.

Conflicts of Interest: The authors declare no conflict of interest.

7. REFERENCES

[1] A. Bouafassa, L. Rahmani, and S. Mekhilef, "Design and real time implementation of single phase boost power factor correction converter," ISA Trans., vol. 55, pp. 267–274, Oct. 2014.

[2] A. Kessal and L. Rahmani, "Analysis and design of sliding mode controller gains for boost power factor corrector," ISA Trans., vol. 52, no. 5, pp. 638–643, Jun. 2013.

[3] Z. Botao, W. Qi, and Z. Min, "Analytical solution for output voltage ripple coefficient of boost converter," Electrical Engineering, Jan. 2022.

[4] IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, IEEE Std. 519, 2014.

[5] C. H. K. Jensen, R. B. Lind, J. C. Hertel, A. M. Ammar, A. Knott, and M. A. E. Andersen, "A Time-Based Control Scheme for Power Factor Correction Boost Converter," 2019 IEEE Nord. Circuits and System conference Proc., 2019.

[6] J. R. Ortiz-castrillón, G. E. Mejía-ruíz, N. Muñoz-galeano, J. M. López-lezama, and S. D. Saldarriaga-zuluaga, "PFC Single-Phase AC / DC Boost Converters: Bridge, Semi-Bridgeless, and Bridgeless Topologies," Aug. 2021.

[7] I. Kocaarslan, S. Kart, N. Genc, and H. Uzmus, "Design and application of PEM fuel cell-based cascade boost converter," Electr. Eng., vol. 101, no. 4, pp. 1323–1332, Nov. 2019.

[8] H. Calik, G. Yalcin, and E. Sehirli, "Power Factor Correction in Induction Heating System Using PFC Boost Converter," Eur. J. Tech., vol. 10, no. 2, pp. 464–475, Nov. 2020.

[9] O. Turksoy, U. Yilmaz, and A. Teke, "Efficient AC-DC power factor corrected boost converter design for battery charger in electric vehicles," Energy, vol. 221, p. 119765, Jan. 2021.

[10] M. A. Senol, "Fuzzy Logic Based Power Factor Correction in Single Phase AC-DC System," Bitlis Eren Üniversitesi Fen Bilim. Derg., vol. 10, no. 2, pp. 602–612, April. 2021.

[11] O. Maroufi, A. Choucha, and L. Chaib, "Hybrid fractional fuzzy PID design for MPPT-pitch control of wind turbine-based bat algorithm," Electr. Eng., vol. 102, no. 4, pp. 2149–2160, May. 2020.

[12] H. Arpaci, "Fractional Model Reference Adaptive PIλDμ Control," J. New Results Sci., vol. 5, no. 11, pp. 102–117, Dec. 2016.

[13] F. Ahmad and M. Demitas, "Fractional PI Controller to Correct the Power Factor for Variable Loads," in 1st ICEANS 2022 Konya, Turkey, 2022, pp. 1339–1342.

[14] T. W. Versloot, D. J. Barker, and X. O. One, "Optimization of Near-Field Wireless Power Transfer Using Evolutionary Strategies," Esa.Int, pp. 2436–2440.

[15] T. Thabet and D. John, "An Approach to Calculate the Efficiency for an N-Receiver Wireless Power Transfer System," Int. J. Adv. Comput. Sci. Appl., vol. 6, no. 9, pp. 91–98, Nov. 2015.

[16] J. Wang, S. L. Ho, W. N. Fu, and M. Sun, "Analytical design study of a novel witricity charger with lateral and angular misalignments for efficient wireless energy transmission," IEEE Trans. Magn., vol. 47, no. 10, pp. 2616–2619, Oct. 2011.

[17] I. Okasili, A. Elkhateb, and T. Littler, "A Review of Wireless Power Transfer Systems for Electric Vehicle Battery Charging with a Focus on Inductive Coupling," Electron., vol. 11, no. 9, April 2022.

[18] Huang Xueliang, J. Qingjing, T. Linlin, W. Wei,

Z. Jiaming, and Z. Yalong, “Study on Series-Parallel Model of Wireless Power Transfer via Magnetic Resonance Coupling,” Trans. CHINA Electrotech. Soc. Vol.28, vol. 28, no. 3, pp. 171–176, Mar 2013.

[19] F. Ahmad and M. Demirtas, “Fractional Order PI Controller for Wireless Power Transfer with High Efficiency,” in 3rd ICAENS, July 20-23, 2022, Konya, Turkey, 2022, pp. 1085–1089.

[20] K. Ding, “Active power factor correction using sliding mode control with reaching law,” ICIEA 2007: 2007 Second IEEE Conference on Industrial Electronics and Applications, May 23-25, 2007.

[21] Lloyd Dixon, “Average Current Mode Control of Switching Power Supplies,” Proc. Intersec. Energy Convers. Eng. Conf., vol. 1, pp. 218–223, 1991.

[22] P. R. Mohanty and A. K. Panda, “Fixed-Frequency Sliding-Mode Control Scheme Based on Current Control Manifold for Improved Dynamic Performance of Boost PFC Converter,” IEEE J. Emerg. Sel. Top. Power Electron., vol. 5, no. 1, pp. 576–586, March. 2017.

[23] Y. Yan, W. Shi, and X. Zhang, “Design of UAV wireless power transmission system based on coupling coil structure optimization,” Eurasip J. Wirel. Commun. Netw., vol. 2020, no. 1, March. 2020.

[24] N. Ramsaroop and O. O. Olugbara, “Wireless power transfer using harvested radio frequency energy with magnetic resonance coupling to charge mobile device batteries,” Appl. Sci., vol. 11, no. 16, Aug. 2021.

[25] Y. Liu, J. Fan, T. Zuo, Y. Zhang, L. Dong, and J. Liu, “Simulation study on series model of wireless power transfer via magnetic resonance coupling,” Proc. 2017 IEEE 3rd Inf. Technol. Mechatronics Eng. Conf. ITOEC 2017, vol. 2017, pp. 191–195, Oct. 2017.

[26] H. S.-R. Silva-Ortigoza, Control Design Techniques in Power Electronics Devices. Springer; 2006 edition, pp. 20-30.

[27] E. Ilten and M. Demirtas, “Fractional order super-twisting sliding mode observer for sensorless control of induction motor,” COMPEL - Int. J. Comput. Math. Electr. Electron. Eng., vol. 38, no. 2, pp. 878–892, Jan. 2019.

[28] M. Çelebi and A. B. Aşçi, “Fractional order control of a sinusoidal output inverter,” Istanbul Univ. - J. Electr. Electron. Eng., vol. 16, no. 2, pp. 3037–3042, May. 2016.

[29] R. El-Khazali, “Fractional-order $PI^{\lambda}D^{\mu}$ controller design,” Comput. Math. with Appl., vol. 66, no. 5, pp. 639–646, Sep. 2013.

[30] H. Calgan and M. Demirtas, “A robust LQR-FOPIλDμ controller design for output voltage regulation of stand-alone self-excited induction generator,” Electr. Power Syst. Res., vol. 196, no. March, p. 107175, March. 2021.