

Investigation of Power Factor Improvement for Non-Linear Furnace Inverter

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Abstract

Advanced technology is required to support the needs of metal manufacture in shaping many various products. An electrical furnace with inverter topology is one of example advanced technology application to melt and alloy metals and refractories. However, a furnace inverter is a non-linear load that creates voltage and current harmonics in the electrical network. Harmonics generate distortions and voltage variations in the electrical grid and it makes the grid is out of balance. Another effect of an electric furnace is a decrease in power factor, resulting in reduced electrical efficiency as well as transformer capacity. In this works, a model investigation and analysis are carried out to combine a active power factor correction and active hybrid filters to get the best outcomes for better furnace inverter performance to the electrical grid. The furnace inverter is modeled in equivalent power and control circuit to deliver the matched value in power factor with 1-3 percent difference to manufacturing data equipment. The results of the experiment show that the proposed model for the modified furnace has delivered the improving electrical power quality in the power factor by 13 percent to 17 percent. The other promising results are a reduction in power distortions, sag, and swell.

Keywords

Furnace Inverter, Power Factor, Active Power Factor Correction, Active Hybrid Filters

1. Introduction

Power quality problem caused by non-linear loads are greatly reduced when power conversion components with multiple component combinations are used. Induction furnaces that impart enough harmonic currents into the grid

system, causing unbalanced voltage disturbances and voltage regulation in the power grid, resulting in a decrease in the power factor of the induction furnace system (Saggu. T. S, Singh. L, and Gill. B, 2016). The lagging power factor and current harmonics of these transformers cause increased power losses and contribute to the transformer's required score of power. The furnace current power factor is normally assessed on the transformer's primary coil. As a result, the supplier of the power factor drop, that is the furnace, is obscured and impacted by the transformer. To use the furnace and return to a stable mode of operation in steel melting operations, controller action is required (Czarnecki. L. S, et al, 2018). The power system is charged for each kVAr factor expended, the target power factor is close to 1 (Laketi. N, 2017)

Based on the description above, this work intends to carry out modeling of the furnace inverter circuit to improve the quality of electrical power factor at PT Texmaco Perkasa Engineering Semarang, where a set of rectifiers and snubber inverters are the main 3 electrical equipment of production. Further investigation is conduction implementing several experimental tests on the circuit model of the furnace. The performance of the power factor, active and reactive power measurement is obtained and analyzed by presenting the test conditions voltage, and current (Klyuev. R, Turluev. R, and Khadzhiev. A, 2020). The works are also present the use of the addition of additional active power factor correction and active hybrid filters, to provide the best results in power quality

1.1 Objectives

This study models the combination of power factor correction and an active hybrid filter to increase the power factor of the furnace inverter

2. Literature Review

2.1. Furnace Inverter

A furnace Inverter is a melting metal. It generates heat by an alternating current coil, a process known as electromagnetic induction (Narnaware. P. S and Thosar. A. G, 2016). The furnace converter is integrated to the utility grid through the reactor in the furnaces. Because of these constraints, increasing the voltage at the reference electrode generates electrical input power into the furnace (Yakimov. I. A, et al., 2018).

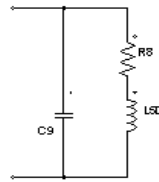


Figure 1. Furnace Inverter

2.2. Power Factor

Power factor represents the phase difference between current and voltage. The power factor ranges between 0 and 1. The power factor at non-linear loads is defined as the average of active power to apparent power. It examines the effectiveness with which electrical power is utilized. The power factor (PF) is compared active power (kW) to apparent power (kVA). Most furnace operations necessitate the use of lagging and unity power factors (Das. J. C, 2017).

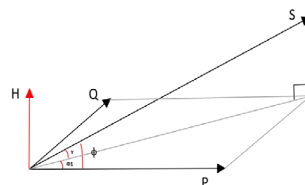


Figure 2. Power Triangle

2.3. Active Power Factor Correction

Active power factor correction is a technique for improving the power factor of a power supply. Compared with other types of high-frequency power factor correction active, overload protection, constant current correction, and overvoltage protection are all included. The output voltage active power factor correction active is lower than the peak voltage, which is usually desirable (Kouzou. A, 2018)

2.4. Active Hybrid Filters

A active hybrid filters is a more value alternative than an active filter because a passive filter can perform principal harmonics (for example, orde 5 and 7) while an active filter reduces other harmonics. In moreover to harmonic current reduction, this type of filter can detect power factor (Lagăr. A. G, et al. 2019) Active hybrid filters generally use resistive element (R), capacitive component (C), and Op-Amp components. The filter results will be bettering as there is a component to amplify a signal of current and voltage called an op-amp.

3. Methods

In this study, experimental methods are expected to be able to answer these problems. The research was conducted using software, with the observed parameters including power factor and its improvement by adding an active hybrid filter and active power factor correction.

3.1. Furnace Inverter Model

The design of this simulation based on the following data is valuable for the voltage of the D/Y transformer per phase is $V1 = 597 \text{ V}$, and $V3 = 567 \text{ V}$. From the input value, the reactive power (Q) is $Q = 321 \text{ VAR}$. The active power (P) is $P = 1.7 \text{ KW}$ and the apparent power obtained is $S = 3.2 \text{ KVA}$.

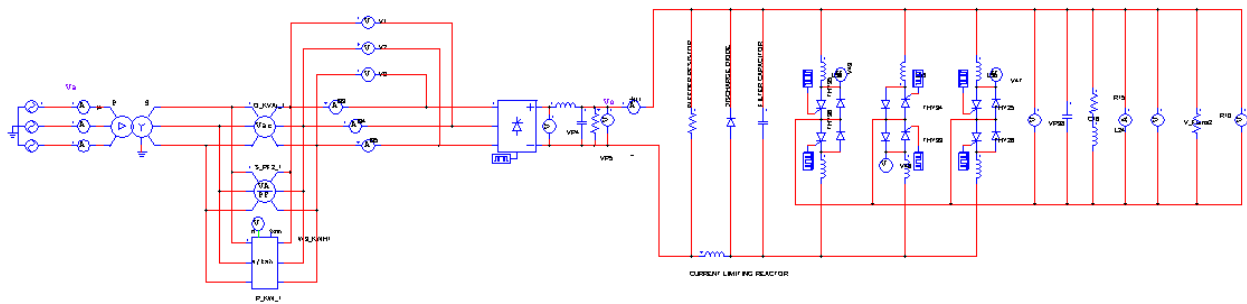


Figure 3. Modelling the furnace inverter system simulation

Figure 3. Shows modeling the furnace inverter system simulation. The inverter converts the alternating current input voltage, which is rectified using a three-phase bridge rectifier with a thyristor circuit, into a direct current output voltage, which is then converted back into an alternating current voltage using the SCR panel inverter circuit. The inverter thyristor consists of six SCRs, and the SCR diodes are being reduced naturally by the AC flowing through the circuit resonant.

3.2. Electric Power in Furnace Inverter System

The furnace inverter load is non-linear loads as this load makes the source side have a non-sinusoidal waveform (Rosa. F. C. D. E. L. A, 2015). The equation defines active and reactive power. Furthermore, the complex power and distortion power will be being defined in the equation.

If the voltage and current in the power system are distorted, the equation that can be derived for the instantaneous voltage by

$$v(t) = V_{m1} \sin(\omega t + \phi_1) + V_{m2} \sin(2\omega t + \phi_2) + V_{m3} \sin(3\omega t + \phi_3) \dots \dots \dots (1)$$

While the current equation can be expressed by

$$i(t) = I_{m1} \sin(\omega t + \theta_1) + I_{m2} \sin(2\omega t + \theta_2) + I_{m3} \sin(3\omega t + \theta_3) \dots \dots \dots (2)$$

The rms value of the above current can be determined by the equation

$$I = \sqrt{I_1^2 + I_3^2 + I_5^2 + I_7^2} \dots \dots \dots (3)$$

Reactive power is the power required for the formation of a magnetic field or the power generated by an inductive load, given in the following equation :

$$Q = \frac{1}{T} \int_0^T P(t) dt \dots \dots \dots (4)$$

$$= \sum_{h=1}^{h=\infty} V_h I_h \sin(\theta_h - \delta_h) = \sum_{h=1}^{\infty} Q_h \dots \dots \dots (5)$$

Active power required by the load is then calculated using the following relation :

$$P = \frac{1}{T} \int_0^T P(t) dt \dots \dots \dots (6)$$

$$= \sum_{h=1}^{\infty} V_h I_h \cos(\theta_h - \delta_h) = \sum_{h=1}^{\infty} P_h \dots \dots \dots (7)$$

and apparent power can be defined as follows:

$$S^2 = P^2 + Q^2 + H^2 \dots \dots \dots (8)$$

or

$$S^2 = P^2 + Q^2 + D^2 \dots \dots \dots (9)$$

The power factor equation is shown as follows:

$$PF = \frac{P}{S} \dots \dots \dots (10)$$

3.3. Active Power Factor Correction Model

The active power factor correction method is suitable for power supplies rated at more than 100W. This technique provides corrections that are more efficient, lighter.

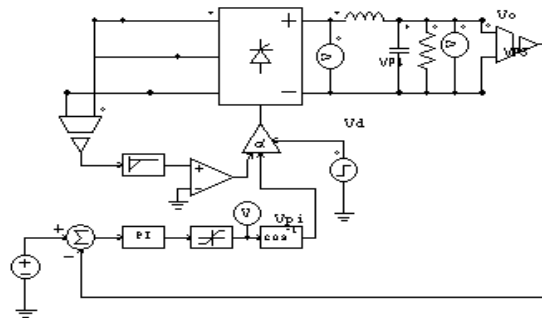


Figure 4. Active power factor correction circuit simulation

Figure 4 Active power factor correction presents a series of power factor corrections. With actives modeling, power factor correction using buck power factor corrections, but a DC to DC buck converter can use between the rectifier and filter capacitor after the full-bridge rectifier buck inductor is connected to an alpha controller for the thyristor switch/bridge delay angle.

3.4. Active Hybrid Filters Model

The goal of this simulation is to create a furnace inverter design that will improve the power factor by utilizing a active hybrid filters. Active filtration refers to a variety of schemes for correction for the frequency generated by the furnace by using series-connected and shunted electronic power converters (Namaware. P. S and Thosar. A. G, 2016).

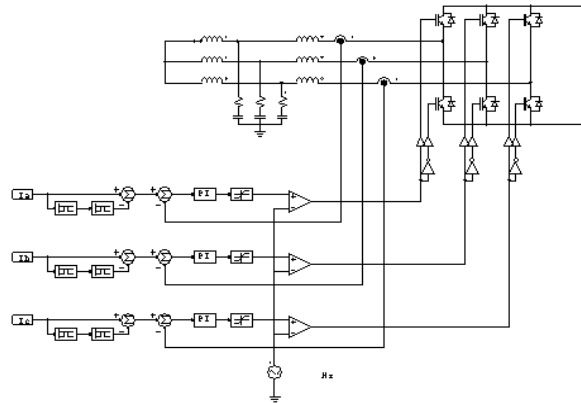


Figure 5. Active Hybrid filters circuit simulation

Figure 5. An active hybrid filters is a signal generator that creates a signal with the same wave amplitude and harmonic wave amplitude as the input signal but in opposite directions. Harmonic currents were also eliminated using the PI control.

The design formula for a single tuned passive filter can be derived, by:

$$C = \frac{Qc}{2\pi f v^2} \dots \dots \dots (11)$$

To determine the inductance of the inductor (L) is as follows :

$$L = \frac{1}{(2\pi f)^2 c} \dots \dots \dots (12)$$

4. Results and Discussion

In the furnace inverter simulation modeling using two models, with different capacities that produce different power and power factor values, as follows :

4.1. Comparison of Factory Power Factor Data with Simulation

From the power factor data at the PT. Texmaco Perkasa Engineering factory which will compare with the simulation results of the furnace inverter system modeling in software follows :

Tabel 1. Comparison Of Power Factor 1-ton

Load (Kilogram)	Power Factor for 1 Ton Load		
	Data Factory	Simulation Results	Percentage of Similarities
0	0.68	0.693	1%
200	0.67	0.696	2%
400	0.65	0.693	1%
600	0.7	0.692	1%
800	0.7	0.692	1%
1000	0.7	0.74	1%

The table above shows the percentage of the suitability of the simulations modeling the furnace inverter system with a capacity of 1-ton. By adjusting the load on the furnace, the result is that at a load of 0kg = 1%, a load of 200kg = 2%, a load of 400kg = 1%, a load of 600kg = 1%, a load of 800kg = 1%, a load of 1000kg = 1%.

Tabel 2. Comparison Of Power Factor 3 Ton

Load (Kilogram)	Power Factor 3 Ton		
	Data Factory	Simulation Results	Percentage of Similarities
0	0.67	0.693	2%
600	0.68	0.697	2%
1200	0.66	0.693	3%
1800	0.7	0.71	1%
2400	0.7	0.707	1%
3000	0.7	0.692	1%

The table above shows the percentage of the suitability of the simulations modeling the furnace inverter system with a capacity of 3-ton. By adjusting the load on the furnace, the result is that at a load of 0 kg = 2%, a load of 600 kg = 2%, a load of 1200 kg = 3%, a load of 1800 kg = 1%, a load of 2400 kg = 1%, a load of 3000 kg = 1%.

4.2. Analysis of Power Factor Improvement

The power factor analysis on the furnace inverter system is been has adapted to the PT Texmaco Perkasa Engineering Semarang factory will be compared with phase simulation model. After testing the suitability of circuit with the factory, the percentage will be on how well the results in the simulation are.

The power factor that has been generated in the furnace inverter circuit is $PF < 0.8$, which will be repaired with the addition of active power factor correction and the addition of a active hybrid filters designed using an IGBT circuit, active filter, and passive filter. The addition to the circuit intended to increase the power factor value < 0.8 targeted to increase the value to > 0.8 . Apart from is improving the power factor, it will also reduce power distortion caused by harmonics in the circuit which can reduce power quality.

4.2.1. Testing Power Factor on Inverter

Table Power factor test : The power factor test was carried out on a simulation of a 1-ton capacity furnace inverter system, resulting in a power factor value before repairs and after repairs with different loads, as follows :

Table 3. Power factor before and after correction with different loads of 1-ton

Load (Kilogram)	POWER FACTOR 1 TON		
	Before Repair	After Repair	Repair Percentage
0	0.693	0.854	16%
200	0.696	0.854	16%
400	0.693	0.865	17%
600	0.692	0.854	14%
800	0.692	0.839	13%
1000	0.74	0.854	16%

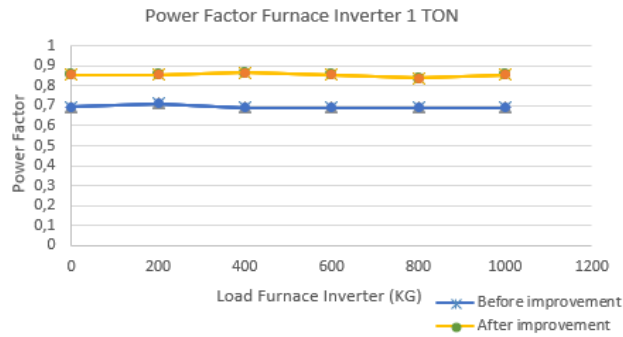


Figure 6. Graph of power factor on 1 ton furnace inverter

Figure 6 The presenting the increase in the power factor value in a furnace inverter circuit with a capacity of 1-ton after repairs were being made. The addition of active power factor correction and a active hybrid filters, in specific, resulted in a power factor value greater than 0.8. From the results above, an increase in the power factor value is greatest when the load is 400 kg with an initial power factor of 0.693 to 0.865.

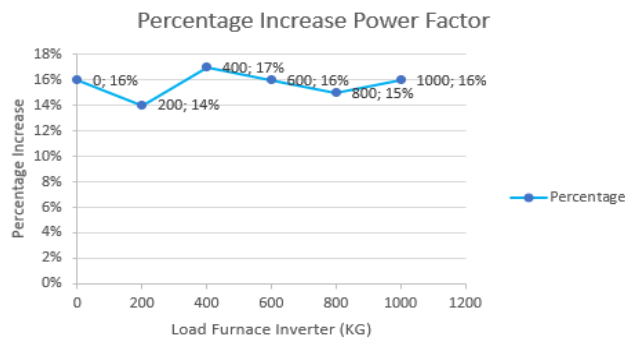


Figure 7. Percentage of power factor increase in 1 ton furnace inverter

Figure 7 The presenting the increase in the power factor value of the circuit simulation on the furnace inverter with different load values, as follows : at 0 kg load an increase of 16%, a 200 kg load an increase of 14%, a 400 kg load an increase of 17%, a 600 kg load an increase of 16%, 800 kg load increased 15%, 1000 kg load increased 16%.

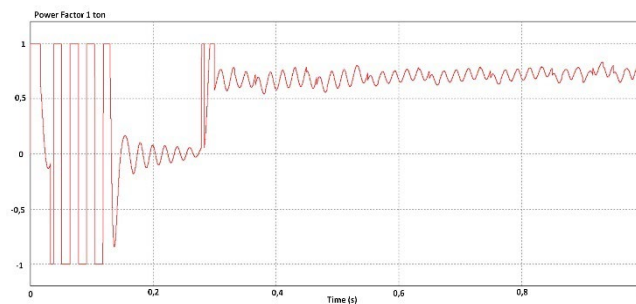


Figure 8. Wave power factor simulation furnace inverter 1 ton

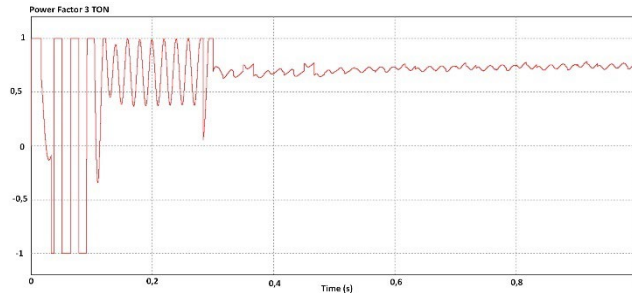


Figure 9. Wave power factor simulation furnace inverter 3 ton

Figure 8 and 9 The presenting is the wave on the power factor that has wave distortion in the form of sags and swells before repairs a made.

Power factor test table : The power factor test was carried outs on a simulation of a 3-ton capacity of furnace inverter system circuit. Table 4 shows the value of are producing a power factor before and after correction with different loads, as follows:

Table 4. Power factor before and after correction with different loads of 3-ton

Load (Kilogram)	POWER FACTOR 3 TON		
	Before Repair	After Repair	Repair Percentage
0	0.693	0.854	16%
600	0.697	0.854	16%
1200	0.693	0.854	16%
1800	0.71	0.854	14%
2400	0.707	0.854	15%
3000	0.692	0.854	16%

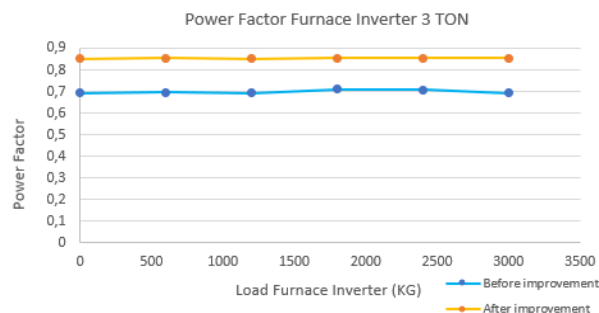


Figure 10. Graph of power factor on 3 ton furnace inverter

Figure 10 The presenting the increase in the power factor value in a furnace inverter circuit with a capacity of 1-ton after repairs were being made. The addition of power factor correction and a active hybrid filters resulted in a power factor value of greater than 0.8. From the results above, an increase in the power factor value is greatest when the load is 1200 kg with an initial power factor of 0.693 to 0.854.

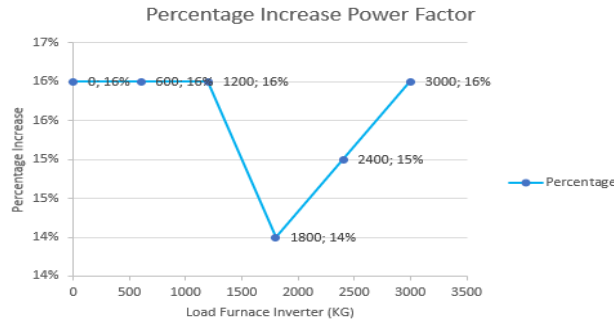


Figure 11. Percentage of power factor increase in 3 ton furnace inverter

Figure 11 Presenting the increase in the power factor value of the circuit simulation on the furnace inverter with different load values, as follows: at 0kg load increased 16%, 600 kg load increased 16%, 1200 kg load increased 16%, 1800 kg load increased 14%, 2400 kg load increased 15%, 3000 kg load increased 16%.

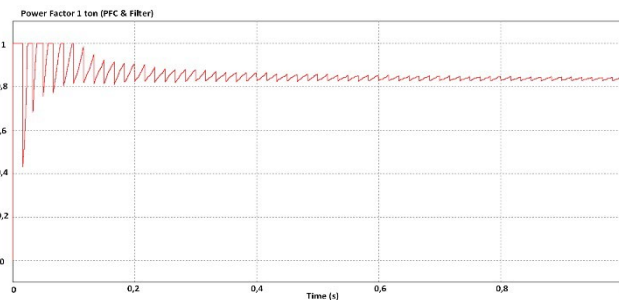


Figure 12. Wave power factor simulation furnace inverter 1 ton

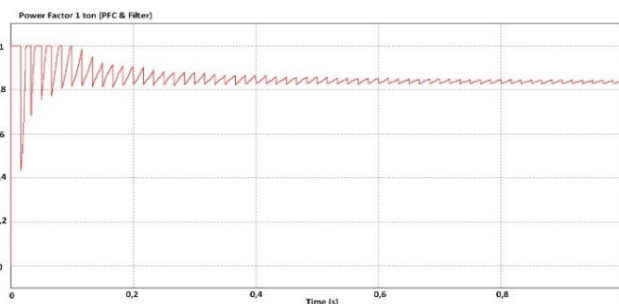


Figure 13. Wave power factor simulation furnace inverter 3 ton

Figure 12 and 13 Presenting the wave on the power factor experienced a reduction in wave distortion in the form of sags and swells after improving the quality power.

5. Conclusion

Several conclusions from the results and analysis are:

- By making improvements, the simulation of the results of the furnace inverter also produces an improvement in power distortion caused by harmonics.
- The results of the simulation model of the furnace inverter have produced a good range of similarities between data factory and experiment in the value of 1% until 3%.
- The addition of active power factor correction and active hybrid filter in the simulation of the furnace inverter circuit resulted in the highest increase in power factor value for a capacity of 1 ton at a load of 400 kg with a active power factor correction from 0.693 to 0.865 or 17% correction. At a capacity of 3-ton with a load of 1200kg, a active power factor correction is successfully made from 0.693 to 0.854 with a 16% increment.

References

- Saggu. T. S, Singh. L, and Gill. B, "Power quality improvement in induction furnace using eleven level cascaded inverter based DSTATCOM," *2016 IEEE Electr. Power Energy Conf. EPEC 2016*, pp. 3–8, 2016, doi: 10.1109/EPEC.2016.7771752.
- Czarnecki. L. S, Almousa. M, and Gadiraju. V. M, "Why the Electric Arc Nonlinearity Improves the Power Factor of Ac Arc Furnaces?," *2018 IEEE Int. Conf. Environ. Electr. Eng. 2018 IEEE Ind. Commer. Power Syst. Eur. (EEEIC / I&CPS Eur.)*, pp. 1–6, 2018.
- Laketi. N, "Power Factor Correction of Electric Arc Furnace Using Active and Passive Compensation," vol. 5, pp. 6–11, 2017.
- Klyuev. R, Turluev. R., and Khadzhiev. A, "Analysis of Power Quality and Pumping Units Operation's Optimization," *Proc. - 2020 Int. Ural Conf. Electr. Power Eng. Ural. 2020*, pp. 324–329, 2020, doi: 10.1109/UralCon49858.2020.9216254.
- Narnaware. P. S and Thosar. A. G, "International Journal of Advance Engineering and Research Power Quality Issues in Induction Furnace," pp. 204–214, 2016.
- Yakimov. I. A, Radionov. A. A, and Maklakova. E. A, "Investigation of electrical characteristics of high-power electric arc furnaces in the mode of stabilizing the primary current of the furnace transformer by means the thyristor regulator in the intermediate circuit," *Proc. 2018 IEEE Conf. Russ. Young Res. Electr. Electron. Eng. ElConRus 2018*, vol. 2018-January, pp. 840–844, 2018, doi: 10.1109/ElConRus.2018.8317219.
- Das. J. C, *Power System Analysis*. 2017.
- Kouzou. A, *Power Factor Correction Circuits*, 4th ed., no. d. Elsevier Inc., 2018.
- Lagár. A, Popa. G. N, and Diniş. C. M, "Experimental Analysis of a High-Frequency Induction Furnace and its Impact on Power Quality," *2019 11th Int. Symp. Adv. Top. Electr. Eng. ATEE 2019*, pp. 1–6, 2019, doi: 10.1109/ATEE.2019.8724861.
- Rosa. F. C. D. E. L. A, *Harminics, Power System, and Smart Grids*. 2015.
- Mondal. A, "Design , Simulation and Comparative Analysis of Control Topologies for Thyristor Power Controllers," *2018 2nd Int. Conf. Power, Energy Environ. Towar. Smart Technol.*, pp. 1–6, 2018.

Biography

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