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Design and Analysis of CPAT for Unified Power Flow Controller Application

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Abstract: The reliability, power quality, line congestion, lines capacity and stability are major issues in transmission and distribution systems for efficient power transmission. The UPFC will provide solutions for these issues. In this paper, we have proposed a Custom Power Active Transformer (CPAT) based unified power flow controller (UPFC) for power flow control and compensation. This proposed system has been design using MATLAB SIMULINK tool. The performance of CPAT's and its capability for providing various UPFC services are investigated. The simulations results have confirmed that it provides the required grid services efficiently.
Keywords: Unified Power Flow Controller, Grid, custom power active transformers, Magnetic circuits, Power control, converter, shunt converter, series converter.

I. INTRODUCTION

There were many obstacles, and technological issues posed by the growing demand for distributed generation to enable substantial grid contributions. Since of the erratic conduct of renewable generation and the ever-increasing need for electrical energy, substation building and operation has undergone many innovations to overcome these challenges[1]. To ensure a efficient, sustainable and smart electric network, integration of monitoring and control functionalities across the power grid, has evolved to meet these demands [2]. Such functionalities were commissioned via power electronic converters which proved to have several beneficial impacts on the distribution network [3-5] and the transmission network [6-8].

Flexible AC Transmission Systems (FACTS) have demonstrated their ability to provide services to support power transmission and power distribution systems effectively and to improve their power system efficiency, consistency and its stability [9]. Of these power systems, the UPFC system is considered to be the most flexible tool for reducing line congestion and increasing the efficiency of existing transmission lines. Connection of power electronics converters system to offer UPFC services has been achieved either through large isolation transformer system, complex multilevel topologies or back to back converters system that handle the rated line power [10-12]. Transformer-less solution involving multilevel topologies emerge from the need to remove bulky isolation transformers system requirement. However, the full rated voltage is needed for multilevel topologies and for this a complex system configuration is required. The transformers system provides isolation and they can be used to connect both shunt and series power devices to power system very efficiently. However, when considering high power compensation systems, size, cost and footprint are a further concern. To resolve these concerns, the incorporation of electronic control devices into a traditional transformer system has been observed in recent literature aimed at the use of off-the-shelf converters system [13-15] or the development of a transformer system based on control electronics [16]. These solutions, however, have either addressed compensation of one type [13], specific applications[14-15] or involve higher power and complex architectures[16]. The CPAT system of monolithic transformer core structure has been proposed and investigated in [17] and [18] and this CPAT integrates the series and shunt power electronics converters to the distribution transformer. The Sen Transformer has be proposed and investigated in [15] and is comparable with CPAT system when combining multiple transformers into the single unit. The shunt services offered by CPAT to power system are compensation of reactive power, elimination of harmonics and mitigation of inrush current in grid. But, the Sen Transformer cannot provide some of these services. But, investigation of CPAT system for single phase applications is carried out and also CPAT system investigation as Unified Power Quality Conditioner (UPQC) for power distribution network.

On the basis of operation principle of a CPAT system the power transmission applications can be realized as it offers auxiliary windings and can be utilized for any of the shunt-series application. Various researchers across the world have been investigated the several methods to resolve the isolation requirement of the power system with the use of transformer-less techniques [19-20] and also they investigated the power electronics based transformers system [10]. Such a system configurations are utilized in several power transmission applications [21-24] and the bulky line transformers system requirement can be avoided for isolation and there

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is creation of challenge in the complexity in the maintenance and design of the power electronics system [25]. Since, bulky power transformers system are an key element in a power network for matching the voltage levels between the different buses, the CPAT system incorporates both series and shunt transformers within these power transformers system. In this case an isolated UPFC system can be built by replacing any power transformer system with a CPAT system using fractional power converters system. Thus, this offers an integrated UPFC system inside any power transformer system.

This paper is organized as follows: in section II the related work is presented. Section III presents the proposed CPAT-UPFC and its design, the simulation results is presented in section IV. Finally, conclusions are summarized in section V.

II. RELATED WORK

H Lee et al [18] 2019 have proposed the novel topology of UPFC with N: 2 transformers. They implemented the 3-phase UPFC using 3-single phase transformers. This system is employed with auto transformer to reduce the power and voltage rating of transformers and switches. The benefits offered by this proposed system are installation spaces and reduction in costs.

M.A. Elsaharty et al [19] in 2018 have investigated the use of power electronics integrated transformer (PEIT) for compensation of power distribution system. They investigated the CPAT system control for unified power-quality controller (UPQC) application to compensate for requirements of reactive power, and mitigate the grid system inrush current. Also, they investigated the control of CPAT system for attenuation of grid current and load voltage harmonics. The CPAT merits and its performance are validated via simulation tool and experimental implementation.

P. Li et al [20] in 2017 have investigated the feasibility for application of MMC-UPFC system in the power grid with 500kv Suzhou power network, in the china. They carried out the simulation to verify and validate the effect on the power flow and voltage regulation and investigated the use of UPFC for regulating can avoid the overload of key transmission section in winter season under heavy load, condition.

Y. Liu, et al [21] in 2016 has carried out the investigation about transformer-less UPFC system for interconnection of two synchronous AC grids system with larger phase difference. This system is constructed from two cascaded multilevel inverters system. With the phase difference determination, we can find real power flow, among two generators

F. Z. Peng et al [22] in 2016 have carried out the design and analysis of transformer-less UPFC system, and this system is constructed using cascaded multilevel inverter system. This proposed system offers benefits like transformer-less, less weight system, offers higher efficiency, higher reliability and lost cost. Such a system is suited for wind power, and solar power transmission.

S. Yang et al [23] in 2016 have design and simulation of transformer-less UPFC system and carried out its major operation such as modulation and control. This proposed system can be installed to obtain maximize energy and optimize energy in grids system, transmission congestion can be reduced and also it can enable high penetration of renewable energy sources.

H. Zhengyu et al[24] in 2000 have investigated the use of UPFC system in the designing of power systems and its modeling, interface and control strategy are investigated to verify the effectiveness and also carried out the case study. They proposed the system with new power frequency model and its performance is improved significantly and fairly power flow control.

III. PROPOSED SYSTEM

A. Proposed CPAT for UPFC

We propose a three phase CPAT called Power Electronics Integrated Transformer based UPFC system. This system can be used to regulate the power flow between primary winding and secondary winding. Also it can be used to compensate the reactive power and for elimination of harmonics in the grid. The figure 1 illustrates the configuration of 3-phase CPAT system and this useful in power transmission system applications. This configuration is constructed using 3-single phase CPATs with grid connected to its primary and secondary windings and 3-phase converter (back to back) is connected to shunt and series windings. This converter will control the shunt winding current and series winding voltage.

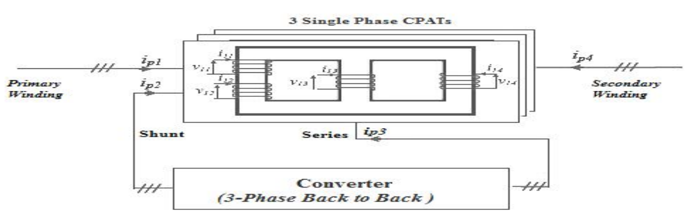

Figure 1 Three-phase CPAT configuration

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The function of shunt converter is to eliminate the harmonic and compensates the reactive power to primary windings. Further, the function of series converter is to control the active and reactive powers through secondary winding. This proposed system is useful in controlling the flow of power among two striff grids. This CPAT system can be designed and analysed to investigate its performance.

B. Proposed System Design

The complete CPAT UPFC were designed using MATLAB-SIMULINK is as shown in figure 2 through figure 4. Its circuits were design using the blocks available in SIMULINK tool. Every block of diagram is taken from libraries and drawn the complete diagram and interconnections are made with the specification. Then the design is saved and it has been further simulated to find out flow of various current, voltage and power.

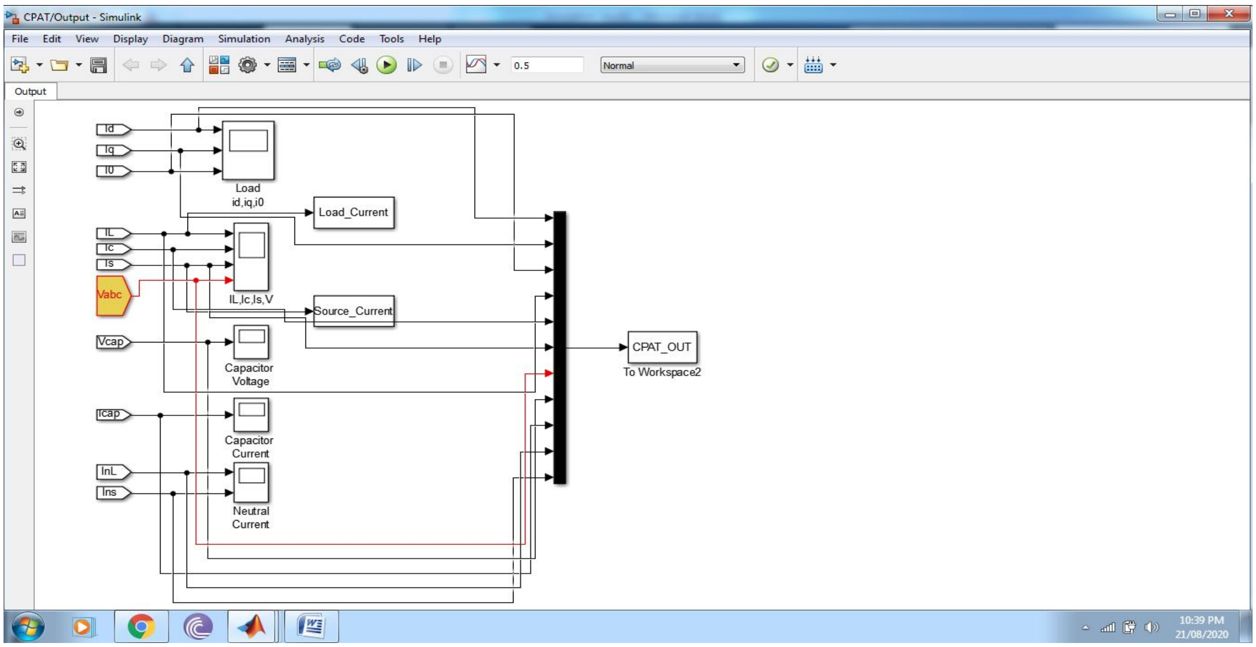


Figure 2 the CPAT configuration

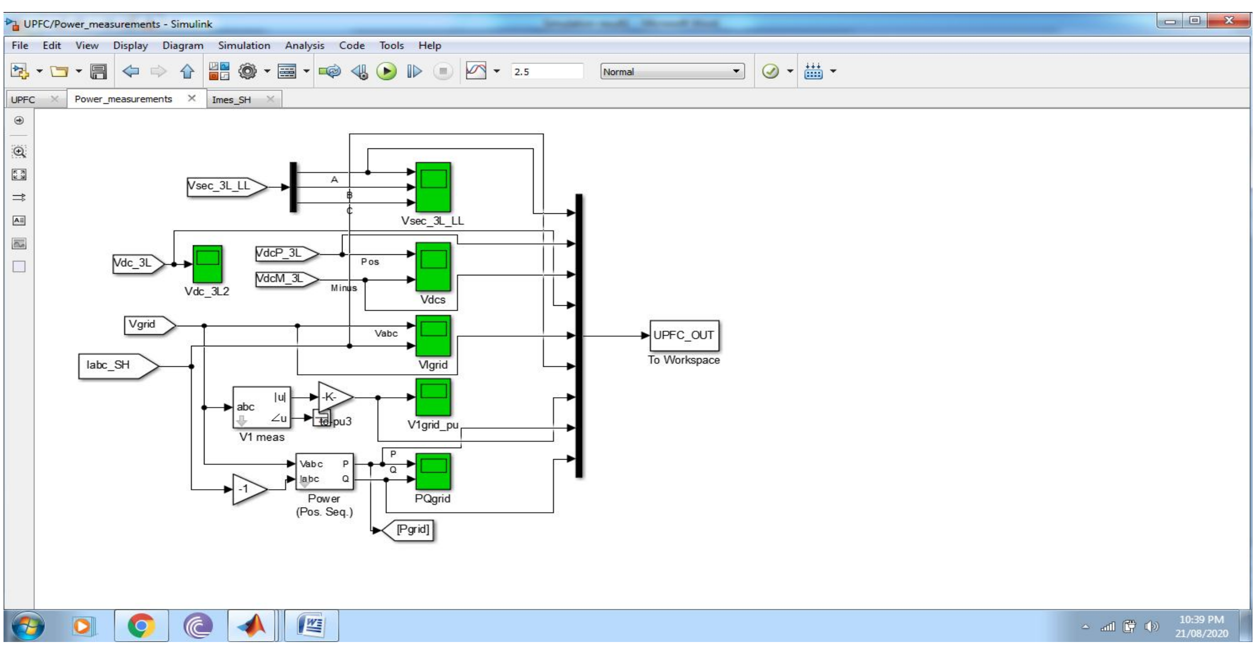


Figure 3 the UPFC power measurement

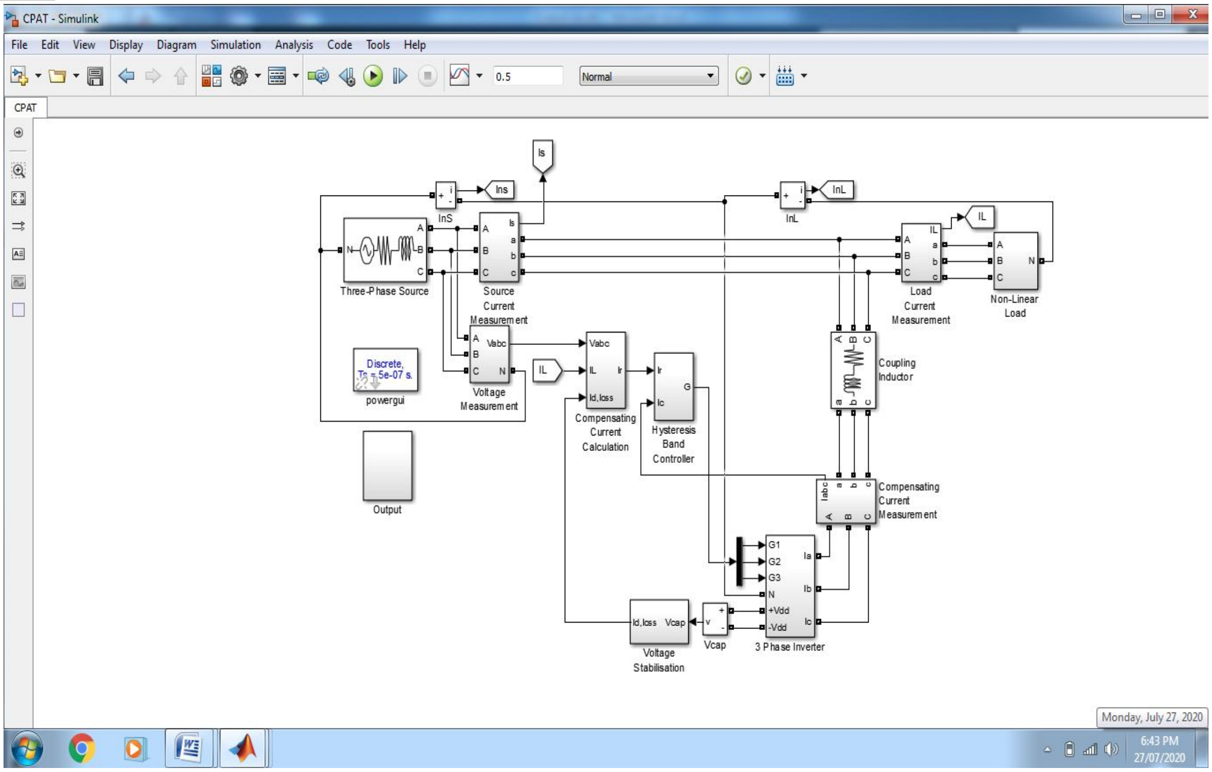


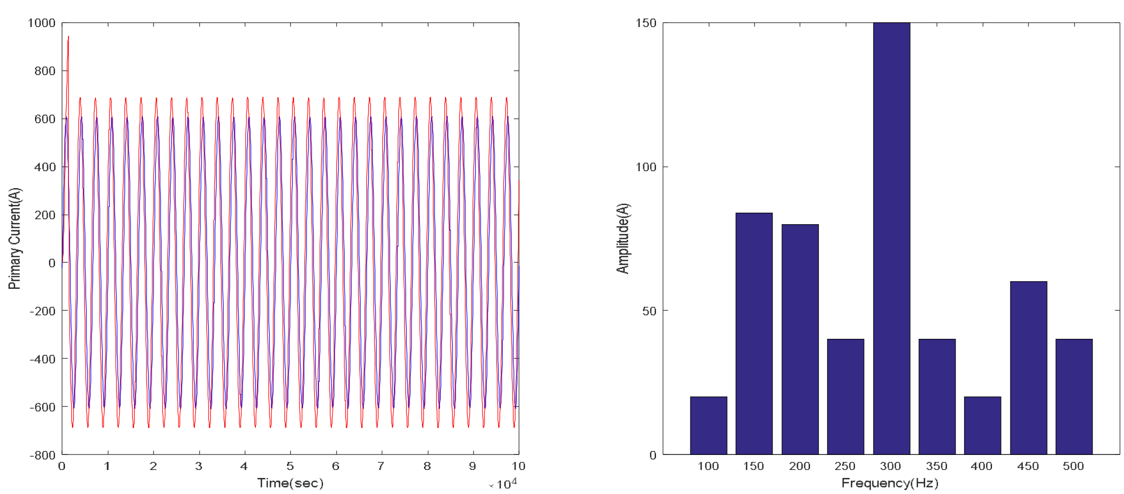
Figure 4 the power flow control

The figure 2 indicates the design of configuration of CPAT and design of UPFC power measurement is shown in figure 3. Further the figure 4 shows the circuit design of power flow control.

IV. SIMULATION RESULTS

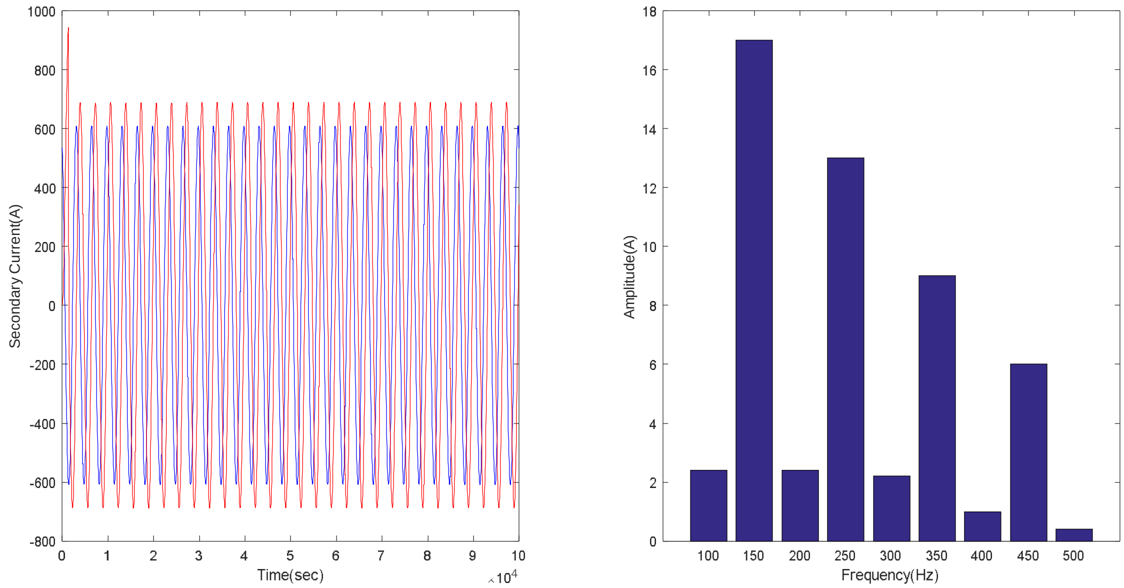
The simulation results of designed CPAT system are shown in terms of snapshots of execution results. To validate the effectiveness of proposed system the simulation analysis were carried out on SIMULINK platform with the use of system parameters like nominal grid voltage of 500KV ,normal system frequency of 50kHz, and nominal DC link power of 200MW.

The figure 5 through figure 8 is the simulated results indicating the primary and secondary current of shunt converter under enabled and disabled mode. Also, it indicates the analysis of harmonics spectrum.



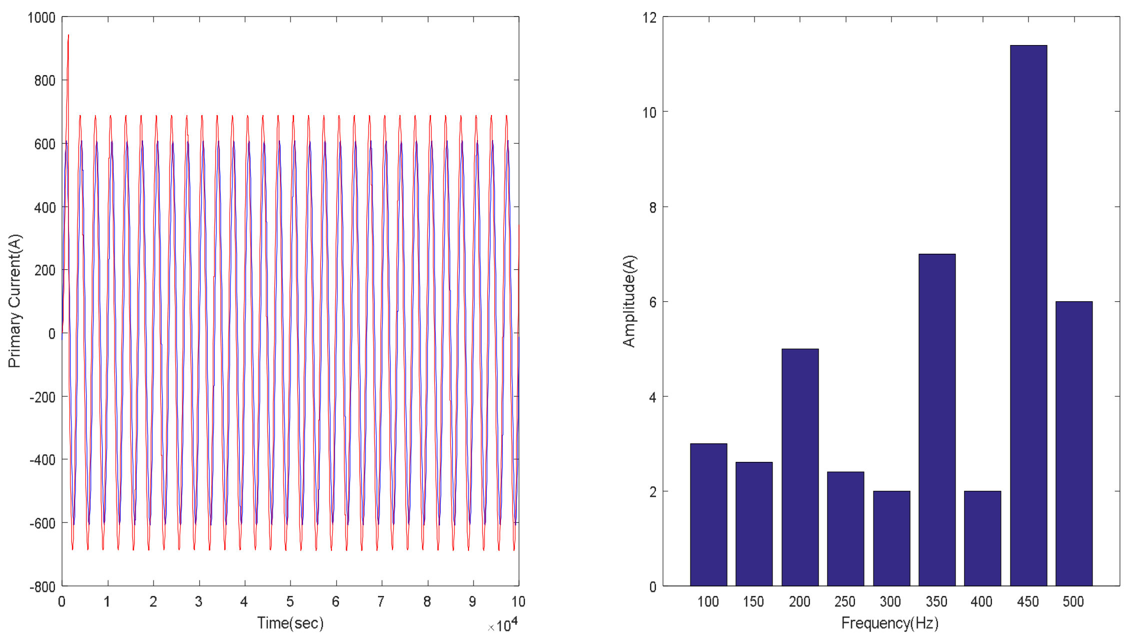
(a) (b)

Figure 5: shunt converter in enabled mode (a) Primary current waveform (b) Harmonics spectrum analysis



(a) (b)

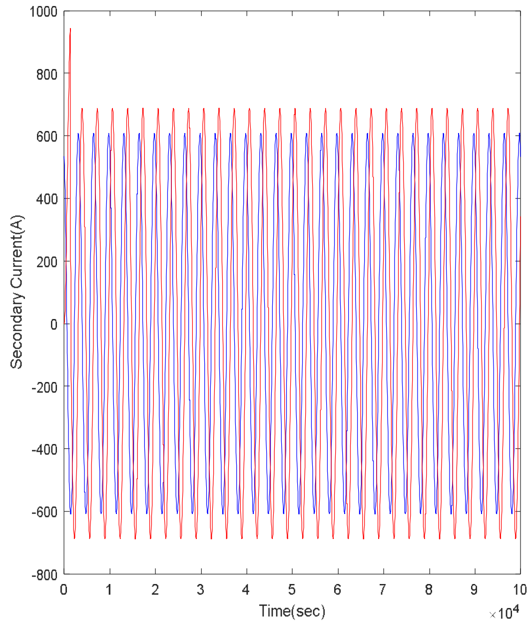
Figure 6: shunt converter in enabled mode (a) Secondary current waveform
(b) Harmonics spectrum analysis

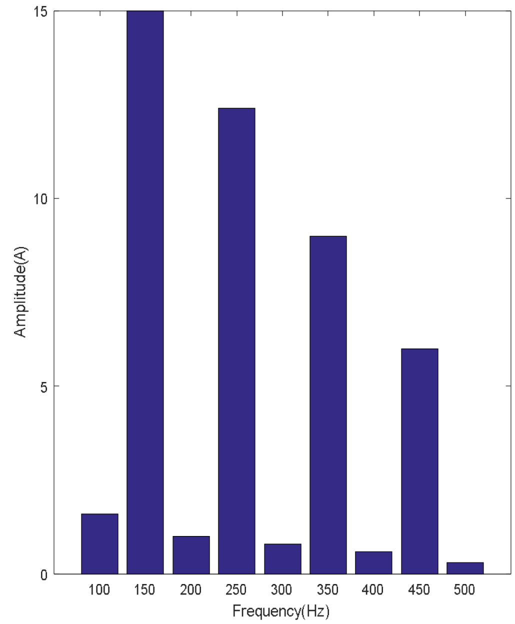


(a) (b)

Figure 7: shunt converter in disabled mode (a) Primary current waveform
(b) Harmonics spectrum analysis

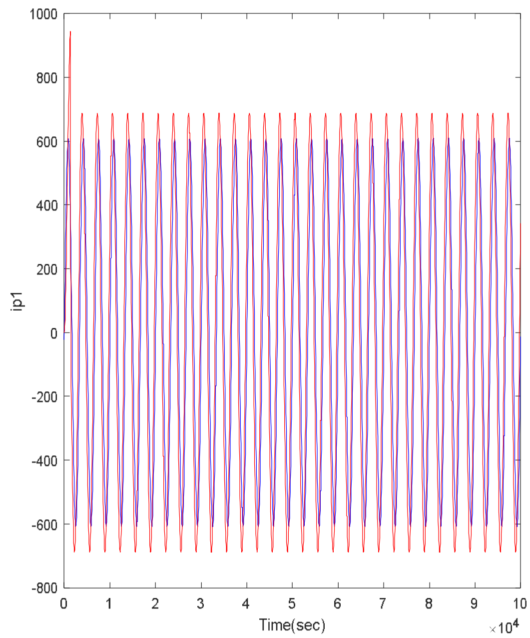
The figure 9 and figure 10 illustrates the waveform of ip1 and ip1 current and its harmonics spectrum analysis graph for all controllers under enabled mode.

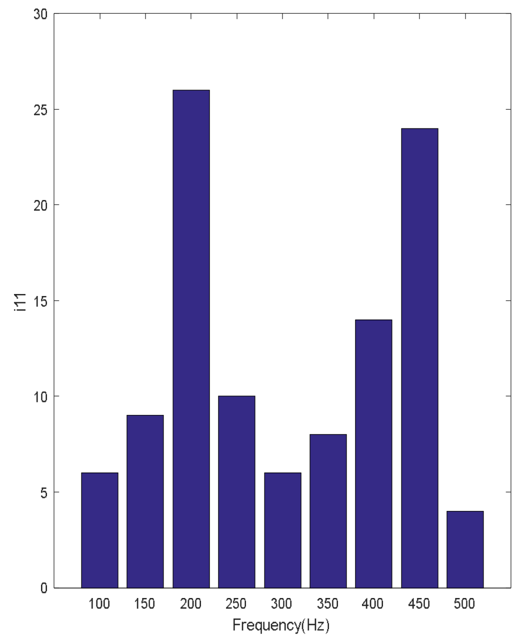




(a) (b)

Figure 8: shunt converter in disabled mode (a) Secondary current waveform (b) harmonics spectrum analysis

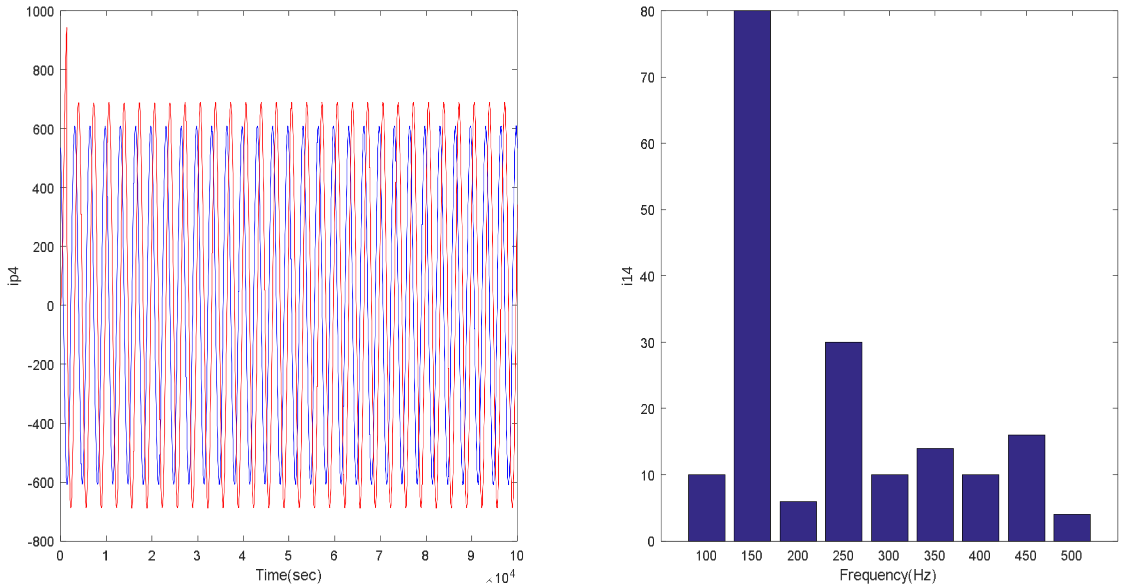




(a) (b)

Figure 9: All controllers in enabled mode (a) ip1 current waveform (b) Harmonics spectrum

The Figure 7 and Figure 8 illustrates the primary current consists of 3rd, 5th and 7th-order harmonics due to no power flow in this scenario, the primary current consists of magnetizing current of CPAT and DC bus regulation current.



(a) (b)

Figure 10: All controllers in enabled mode (a) ip4 current waveform (b) Harmonics spectrum

V. CONCLUSION AND FUTURE WORK

The CPAT-UPFC system has been successfully modelled, analysed and simulated using SIMULINK tool and the control architecture has been evaluated to investigate the CPAT system ability to be function as a UPFC for power distribution systems. The performance analysis and simulation results have been confirmed the effectiveness of CPAT-UPFC system in eliminating grid system harmonic currents and compensation of reactive power of distribution system. Also, it has been verified and validated the control of power flow between two stiff grids system. Hence, this system is efficient for power distribution system application.

Future research work is to design a smart power system using UPFC with low cost equipments and reconfigurable architectures. This system can be analyzed and experimental validated. Also we can develop the UPFC control algorithms.

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