# Performance Analysis of 72-Pulse GTO-based Generalized unified Power Flow Controller Under Power Quality Problems

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***Abstract:*** **With the rapid development and advancement of power electronic devices in recent years changing the scenario in the field of control and handling the power quality issues or problems very effectively by make use of Flexible AC transmission system controllers.The Generalized Unified Power Flow Controller (GUPFC) is a Voltage Source Converter (VSC) based FlexibleAC Transmission System (FACTS) controller for shunt and series compensation among the multiline transmission systems. It can control bus voltage and power flows of more than one line or even a sub-network. This paper presents the complete digital simulation of the improved configurations of GUPFC within the power system is performed in the MATLAB/Simulink environment to handle the power quality issues.The paper proposes a full model comprising of voltage source converter based GUPFC is constructed for digital simulation to investigate the performance of the controller on various power quality problems and observed that considerable improvement is identified on 48,60 and 72-pulse Voltage source converter.**

***Keywords: Voltage source converter, GUPFC, active and reactive compensation, sag and swell, power quality.***

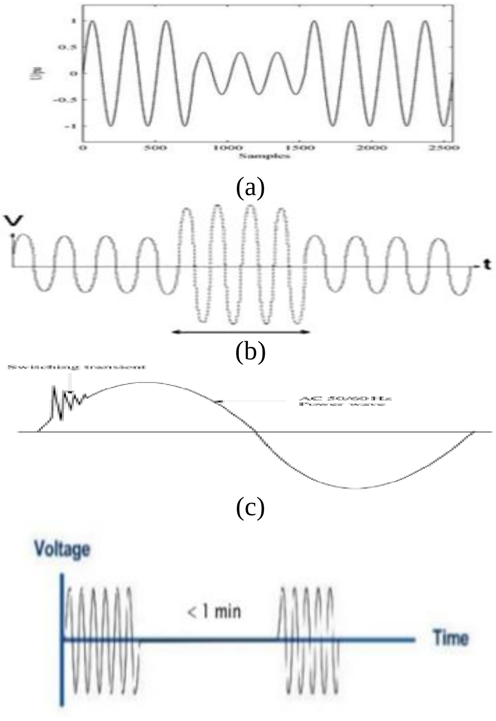
## 1. INTRODUCTION

In the present scenario, most of the power systems in the developing countries with large inter connected networks share the generation reserves to increase the reliability of the power system. However, the increasing complexities of large inter connected networks had fluctuations in reliability of power supply, which resulted in system instability, difficult to control the power flow, existence of voltage sag, voltage swell, interruptions, harmonic distortions, transients and security problems that resulted large number blackouts in different parts of the world which are also called power quality problems[13][21]. The reasons behind the above fault sequences may be due to the systematically errors in planning and operation, weak interconnection of the power system, lack of maintenance or due to overload of the network [5]. In order to overcome these consequences and to provide the desired power flow along with system stability and reliability, installations of new transmission lines are required. However, installation of new transmission lines with the large interconnected power system are limited to some of the factors like economic cost, environment related issues. These complexities in installing new transmission lines in a power system challenges the power engineers to research on the ways to increase the power flow with the existing transmission line without reduction in system stability and security.

In this process, in the late 1980's the Electric Power Research Institute (EPRI) introduced a concept of technology to improve the power flow, improve the system stability and reliability with the existing power systems. This technology of power electronic devices is termed as Flexible Alternating Current Transmission Systems (FACTS) technology. FACTS devices are usually used for fast dynamic control of voltage, impedance, and phase angle of high-voltage ac lines [7]. It devices provide strategic benefits for improved transmission system power flow management through better utilization of existing transmission assets, increased transmission system security and reliability as well as availability, increased dynamic and transient grid stability, and increased power quality for sensitive industries, islanded and grid connected mode operated systems[19][20] (e.g., computer chip manufacture).

The FACTS devices can be categories as shunt, series, series-series and combine shunt-series controllers [7]. By the use of such controllable devices, line power flows can be changed in such a way that thermal limits are not violated, losses minimized, stability margin increased and contractual requirement fulfilled without violating specified power dispatch [9]. Generalized Unified Power Flow Controller (GUPFC),Distributed Power Flow Controller(DPFC) [2][18][21] are one among the different FACTS controllers introduced to improve the power flow control with stability and reliability. It is the most versatile device introduced in early 1990s designed based on the concept of combined series-shunt FACTS Controller. It has the ability to simultaneously control all the transmission parameters affecting the power flow of a transmission line i.e. voltage, line impedance and phase angle [4]. The principle of the proposed converter is verified by PSCAD/EMTDC package. And the circuit model for the GUPFC is developed and simulated by using MATLAB Simulink and PSPICE [8].

Power Quality is the degree to which both the utilization and delivery of electric power affects the performance of electric equipment. The power quality problem can be viewed from two different angles related to each side of the utility meter, namely the Utility and Consumer. An alternative definition of PQ is adopted. A perfect power supply would be one that is always available within voltage and frequency tolerances and has a pure noise-free sinusoidal wave shape [5]. Power Quality means the ability of utilities to provide electric power without interruption. Power Quality has become an important issue since many loads at various distribution ends like adjustable speed drives, process industries, printers, domestic utilities; computers, microprocessor based equipment's etc. have become intolerant to voltage fluctuations, harmonic content and interruptions [13]. Amongst the power quality problems, the supply interruption is, undisputedly, the most severe, since it affects all equipments connected to the electrical grid. Some of power quality problems are described in fig.1




(a) (b) (c) (d)

Figure.1 Waveforms (a) Sag, (b) Swell, (c) Interruption, (d) Transients.

In order to overcome the problems such mentioned above[17], the concept of custom power devices is introduced recently; custom power is a strategy, which is designed primarily to meet the requirements of industrial and commercial customer. The concept of custom power is to use power electronic or static controllers in the medium voltage distribution system aiming to supply reliable and high-quality power to sensitive users. The Generalized Unified Power Flow Controller (GUPFC) is a Voltage Source Converter (VSC) based Flexible AC Transmission System (FACTS) controller for shunt and series compensation among the multiline transmission systems. It can control bus voltage and power flows of more than one line or even a sub-network. This paper presents the complete digital simulation of the improved configurations of GUPFC within the power system is performed in the MATLAB/Simulink [16] environment to handle the power quality issues. The paper proposes a full model comprising of voltage source converter based GUPFC is constructed for digital simulation to investigate the performance of the controller on various power quality problems and observed that considerable improvement is identified on 48, 60 and 72-pulse Voltage source converter.

## 2. PROPOSED MODEL OF GUPFC

The Generalized Unified Power Flow Controller (GUPFC) is a Voltage Source Converter (VSC) based Flexible AC Transmission System (FACTS) controller for shunt and series compensation among the multiline transmission systems of a substation. In this GUPFC is designed by using two series and one shunt voltage sourced converters. The complete digital simulation of the shunt VSC is operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus [11] and two series VSC operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage, while keeping injected voltage in quadrature with current within the power system[6][10].Fig.2 illustrates that Generalised Unified power flow controller.

The 72-pulse voltage source converter is composed of a series double bridge converter and an auxiliary circuit. The converter is established to increase the number of output voltage pulses and decrease the harmonic distortion of output voltage and current [3] [22][23]. Without PWM or increasing the number of bridges, the THD of the converter output voltage can be theoretically reduced.The basic objective of a good VSC scheme is to produce anear sinusoidal ac voltage with minimal wave form distortion or excessive harmonics content.The 24 to 72 pulse converters are obtained by combining 12-pulse voltage source Inverters, with the specified phase shiftbetween converters. For high-power applications with low distortion, the best option is the 72-pulse converter, although using parallel filters tuned to the 23th–25th harmonics with a 24-pulse converter could also be adequately attentive in most applications, but the 72-pulse converter scheme can ensure minimum power quality problems and reduced harmonic resonance conditions on the interconnected grid network. The proposed configuration only needs one injection transformer, so that phenomenon does not exist. Also, decreasing of transformer number is important for saving cost. The converter is operated under fundamental frequency for the main bridges and six time fundamental frequency for the auxiliary circuit, while much higher frequency is needed for PWM. By DC voltage injection, the voltage across the main bridge valves, which are being turned on, is theoretically decreased to zero. Thus the converter switching loses and switching device dynamic voltage stress is reduced significantly. This characteristic is very important for high voltage application.

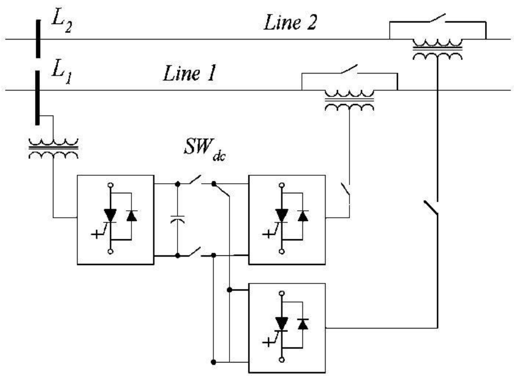



Figure.2. Generalized Unified Power Flow Controller.

The series VSC can work like a SSSC device that is one of the most important FACTS devices for power transmission line series compensation. It is a power electronic-based synchronous voltage generator (SVG) that generates almost three-phase sinusoidal ac voltages, from a dc source/capacitor bank with voltage in quadrature with the reference line current

[14]. The series VSC blocks are connected in series with the transmission line by a series coupling transformer. The series VSC device can provide either capacitive or inductive voltage compensation, if the series VSC-AC voltage lags the line current by $90^0$ , a capacitive series voltage compensation is obtained in the transmission line, and if leads by $90^0$, an inductive series voltage compensation is achieved [1].

## 3. DIGITAL SIMULATION MODEL OF GUPFC WITH 72-PULSE GTO-BASED VSC

The unified ac grid sample system with the GUPFC and its decoupled current controller, for the shunt VSC and control scheme for the two series voltage source converters are connected to four bus system. Fig. 3 shows the single line diagram representing the GUPFC and the host sample grid network. The feeding network are at bus S1 where the voltage source is represented by a 500 kV with 8500 MVA and 300 MW injected load, at bus S3 with 6500 MVA and 200 MW injected load, and at bus S4 with 9000 MVA.

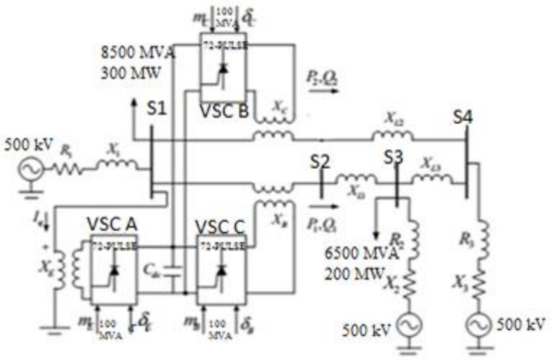



Figure.3. Three-bus system with the 72-pulse GUPFC at busesS2 and S4

The GUPFC located at the left end of the 200km line L2, between the 500kV buses S1 and S4, and 75km line L1,between the 500kV buses S1 and S2, is used to control the active and reactive powers flowing through bus S2 and S4 while controlling voltage at bus S1. It consists of three 100-MVA, three-level, 72-pulse GTO-based converters, one connected in shunt at bus S1 and two connected in series between buses S1 and S2, and buses S1 and S4. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L1 and L2. When the three converters are operated in GUPFC mode, the shunt converter operates as a STATCOM. It controls the bus S1 voltage by controlling the absorbed or generated reactive power while also allowing active power transfer to the two series converters through the DC bus. The reactive power variation is obtained by varying the DC bus voltage. The five three-level shunt converters operate at a constant conduction angle(Sigma=180-3.75=176.25 degrees), thus generating a quasi-sinusoidal 72-step voltage waveform. The first significant harmonics are the 59th and the 61th.

The natural power flow through bus S4 and S2 when zero voltage is generated by the two series converter (zero voltage on converter side of the five converter transformers) is P=+870 MW and Q= -70 Mvar. In GUPFC mode, both the magnitude and phase angle and the two series injected voltages can be varied, thus allowing control of P and Q. The GUPFC controllable region is obtained by keeping the injected voltage to its maximum value (0.1 Pu) and varying its phase angle from zero to 360 degrees. The GUPFC device comprises the full 72-pulse voltage source converter-cascade model connected to the host electric grid network through the coupling transformer. The dc link voltage is provided by the capacitor C[14]. The decoupled current control system ensures full dynamic regulation of the bus voltage (VB), the series voltage injected and the dc link voltage VDC .The 72-pulse VSC generates less harmonic distortion and, hence, reduces power quality problems in comparison to other converters such as (6, 12, 24,36 and 72) pulse. This results in minimum operational overloading and system harmonic instability problems as well as accurate performance prediction of voltage, active and reactive power flow and dynamic stability conditions.

The digital simulation model comprises of Five 12-pulse GTO-converters, phase-shiftedby $3.75^0$from each other and model, can provide the full 72-pulse converter operation. Using a symmetrical shift criterion, the $3.75^0$are provided in the following way: phase-shift winding with $-1.875^0$ on the two coupling transformers of one 24-pulse converter and $+1.875^0$ on two transformers of the second 24-pulse converter and with $-1.875^0$ on two transformers of the other two 24-pulse converter. The firing pulses need a phase-shift of$-1.875^0$, respectively. The 72-pulseconverter model comprises five identical 12-pulse GTO converters interlinked by five 12-pulse transformers with phase-shifted windings. Fig. 4 depicts a schematic diagram of the 72-pulse GTO converters model for shunt VSC, where advanced from 60-pulse GTO as introduced in [12] and with the same method can be found for series VSC. The transformer connections and the necessary firing-pulse logics to get this final 72-pulse operation are modeled. The 72-pulse converter can be used in high-voltage high-power applications without the need for any ac filters due to its very low harmonic distortion content on the ac side. The output voltage have normal harmonics $n$ =$72r\pm1$, where $r$ = 0,1,2,3,…..i.e., $71^{th}$,$73^{th}$,$143^{th}$,$145^{th}$,$215^{th}$,……with typical magnitudes (1/71, 1/$73^{th}$,1/$143^{th}$, 1/ $145^{th}$, 1/$215^{th}$,…..), respectively, with respect to the fundamental; on the dc side, the lower circulating dc current harmonic content is the 60th.

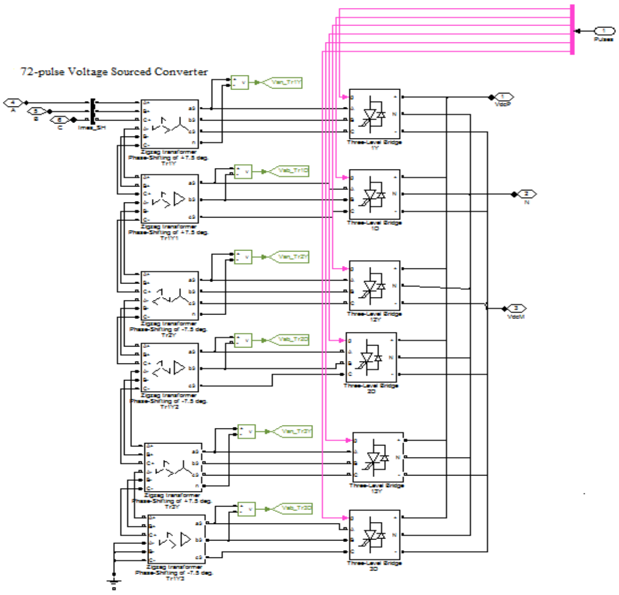



Figure.4. Digital simulation model of 72-pulse voltage source converter.

## 4. Result Analysis

Performance analysis of 72-pulse GUPFC at sag, swell, interruption and transient are described in Fig. 5 to Fig.8

### *A. Voltage Sag*

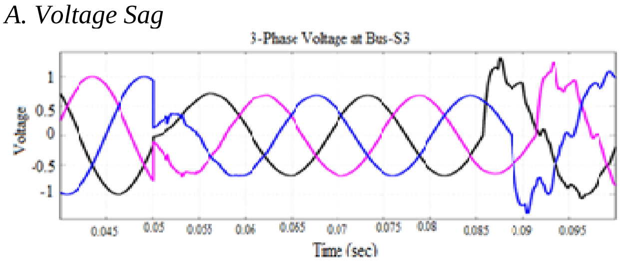



Figure.5a Three-phase voltage sag at bus S3 without FACTS device

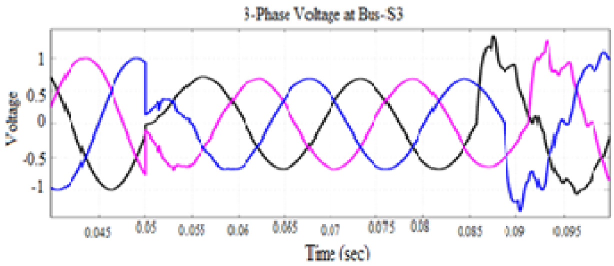



Figure.5b Three-phase voltage sag at bus S3 with 48-pulse GUPFC.

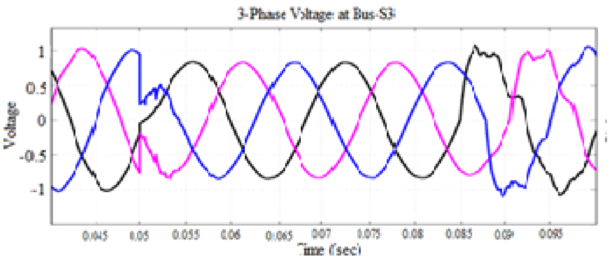



Figure.5c Three-phase voltage sag at bus S3 with 60-pulse GUPFC.

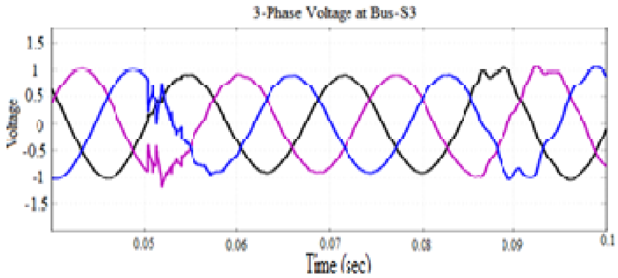



Figure.5d Three-phase voltage sag at bus S3 with 72-pulse GUPFC

### *B. Voltage Swell*

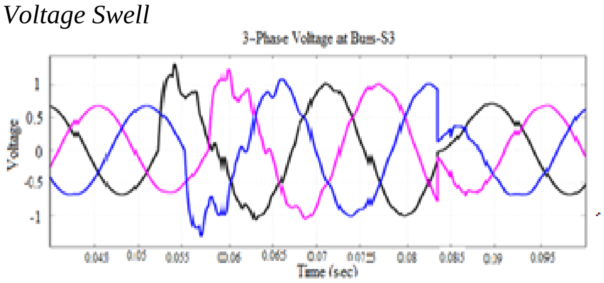



Figure. 6a Three-phase voltage swell at bus S3 without FACTS device

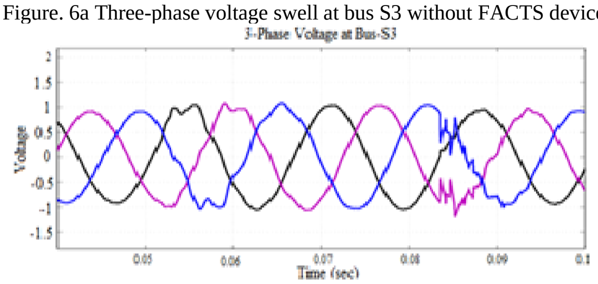



Figure. 6b Three-phase voltage swell at bus S3 with 48-pulse GUPFC

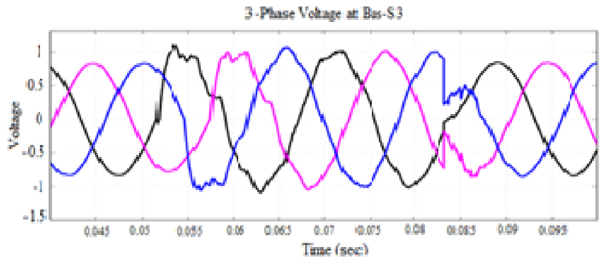



Figure. 6c Three-phase voltage swell at bus S3 (with 60-pulse GUPFC.

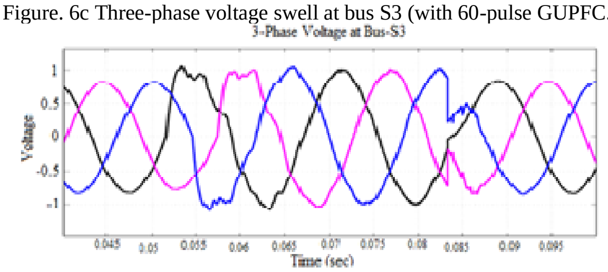



Figure. 6d Three-phase voltage swell at bus with 72-pulse GUPFC

### *C. Temporary Interruptions*

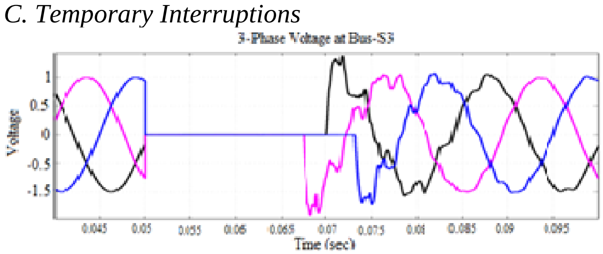



Figure.7a Three-phase voltage interruption at bus S3 without FACTS device.

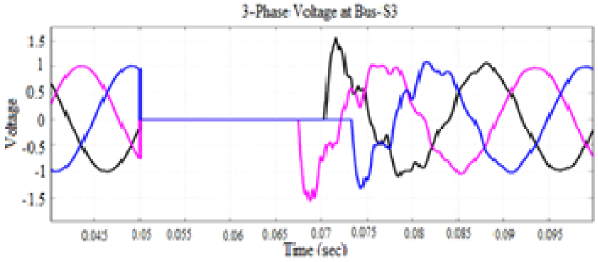



Figure.7b Three-phase voltage interruption at bus S3 with 48-pulse GUPFC.

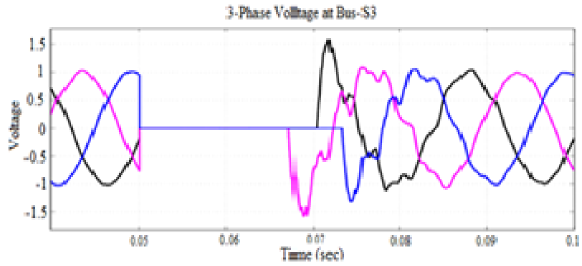



Figure.7c Three-phase voltage interruption at bus S3 with 60-pulse GUPFC.

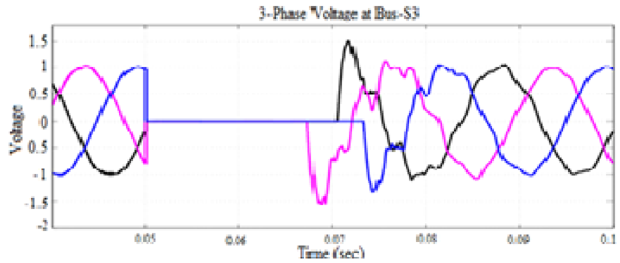



Figure.7d Three-phase voltage interruption at bus S3 with 72-pulse GUPFC.

*D. Transients*

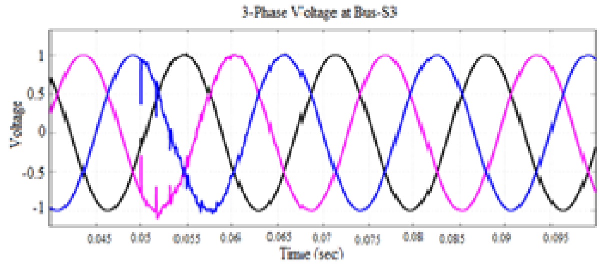



Figure.8a Three-phase transients at bus S3 without FACTS device.

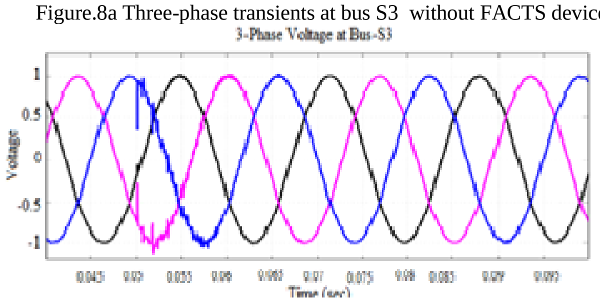



Figure.8b Three-phase transients at bus with 48-pulse GUPFC

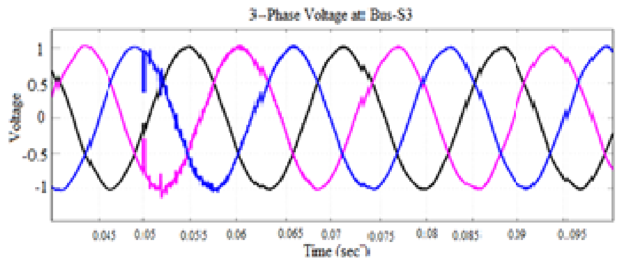



Figure.8c Three-phase transients at bus with 60-pulse GUPFC.

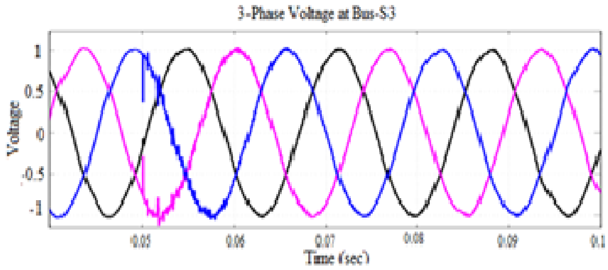



Figure.8d Three-phase transients at bus S3 With 72-pulse GUPFC

Internal performance analysis of shunt compensators are described in Fig. 9 to Fig.11 .

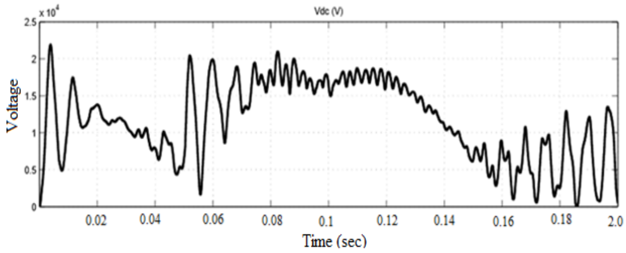



Figure.9a Simulation results of 72-pulse GUPFC shunt compensator for variation in capacitor voltage under voltage sag.

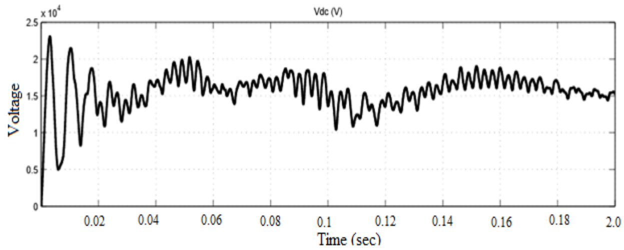



Figure.9b Simulation results of 72-pulse GUPFC shunt compensator for variation in capacitor voltage under voltage swell.

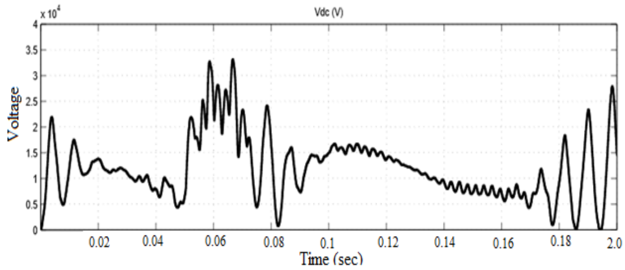



Figure.9c Simulation results of 72-pulse GUPFC shunt compensator for variation in capacitor voltage under interruption.

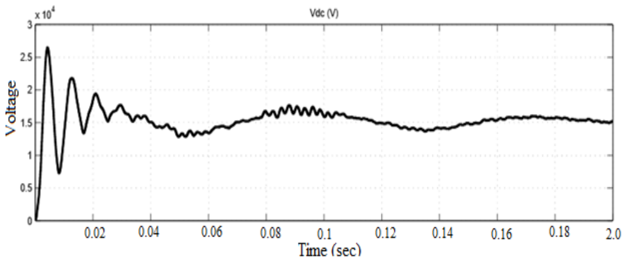



Figure.9d Simulation results of 72-pulse GUPFC shunt compensator for variation in capacitor voltage under transients.

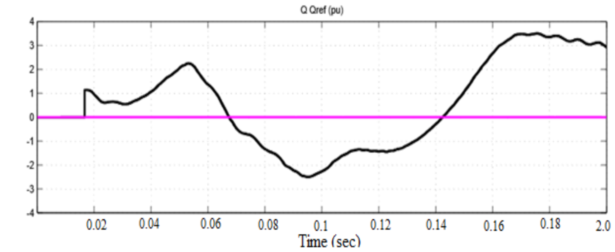



Figure.10a Simulation results of 72-pulse GUPFC shunt compensator for variation in reactive power Q with $Q_{ref}$ under voltage sag.

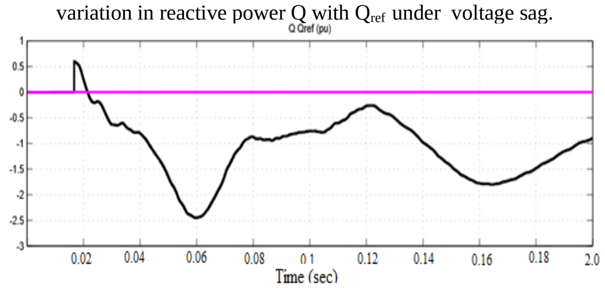



Figure.10b Simulation results of 72-pulse GUPFC shunt compensator for variation in reactive power Q with $Q_{ref}$ under voltage swell.

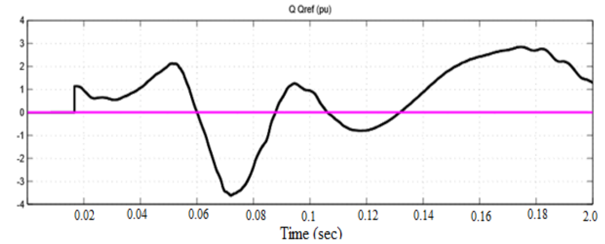



Figure.10c Simulation results of 72-pulse GUPFC shunt compensator for variation in reactive power Q with $Q_{ref}$ under interruption.

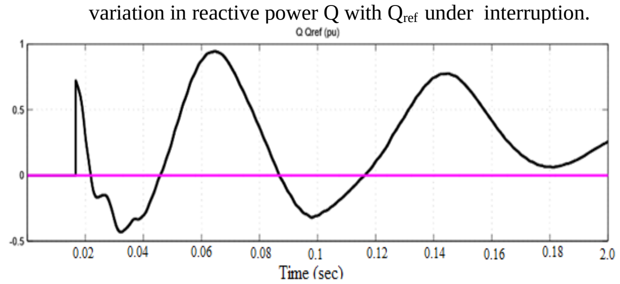



Figure.10d Simulation results of 72-pulse GUPFC shunt compensator for variation in reactive power Q with $Q_{ref}$ under transients.

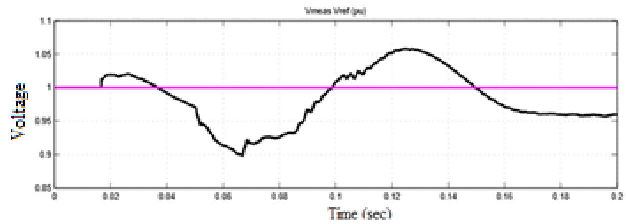



Figure.11a Simulation results of 72-pulse GUPFC shunt compensator for variation in voltage $V_{mean}$ with $V_{ref}$ under voltage sag.

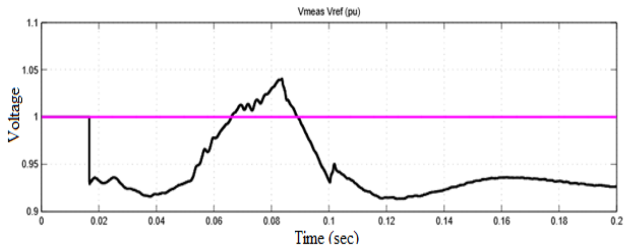



Figure.11b Simulation results of 72-pulse GUPFC shunt compensator for variation in voltage $V_{mean}$ with $V_{ref}$ under voltage swell.

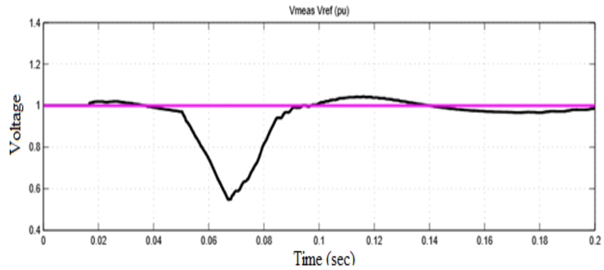



Figure.11c Simulation results of 72-pulse GUPFC shunt compensator for variation in voltage $V_{mean}$ with $V_{ref}$ under interruption.

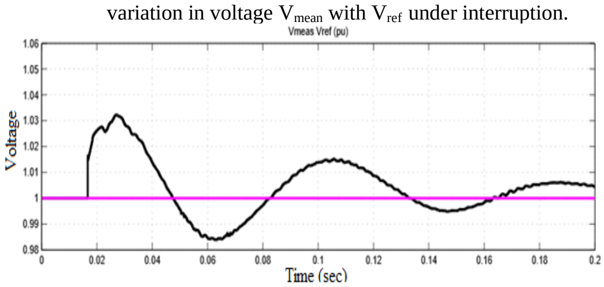



Figure.11d Simulation results of 72-pulse GUPFC shunt compensator for variation in voltage $V_{mean}$ with $V_{ref}$ under transients.

Internal performance analysis of series compensators are described in Fig. 12 to Fig. 16

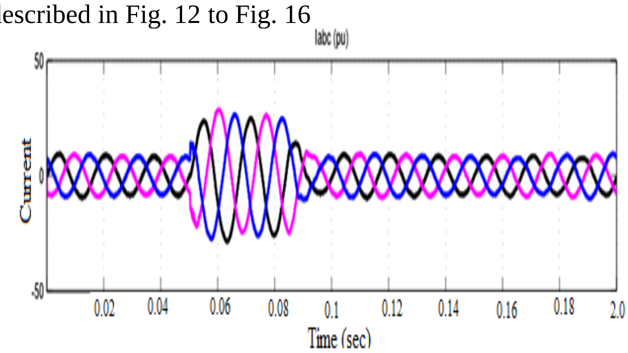



Figure.12a Simulation results of 72-pulse GUPFC series compensator for variation in phase currents under voltage sag.

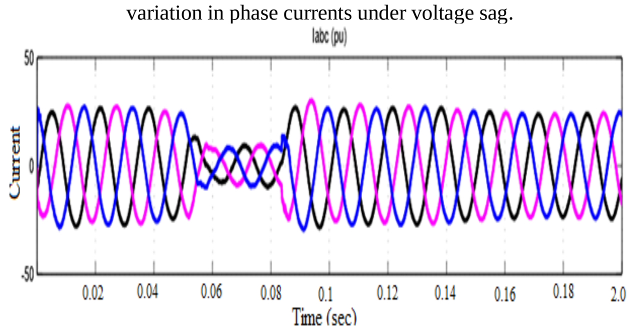



Figure.12b Simulation results of 72-pulse GUPFC series compensator for variation in phase currents under voltage swell.

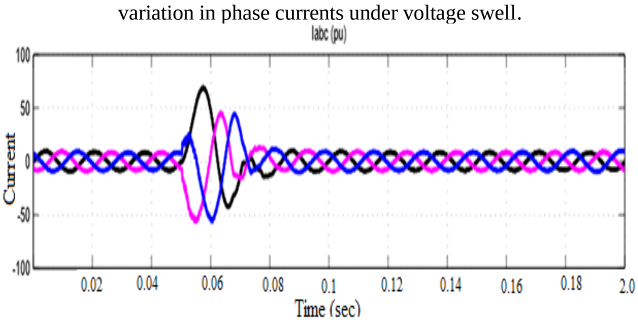



Figure.12c Simulation results of 72-pulse GUPFC series compensator for variation in phase currents under interruption.

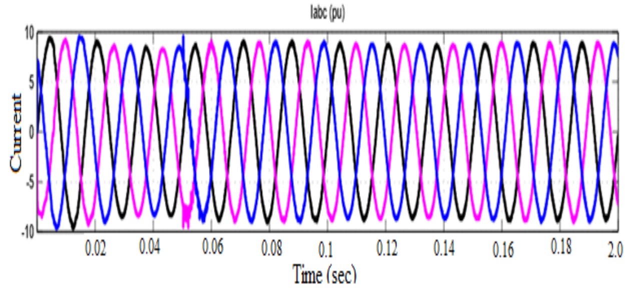


Figure.12d Simulation results of 72-pulse GUPFC series compensator for variation in phase currents under transients.

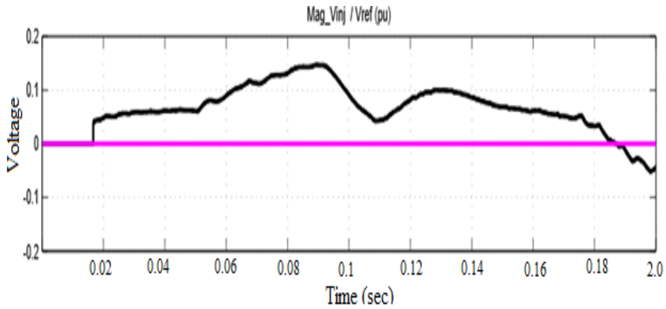


Figure.13a Simulation results of 72-pulse GUPFC series compensator for variation in voltage magnitude of $V_{inj}$ with $V_{ref}$ under voltage sag

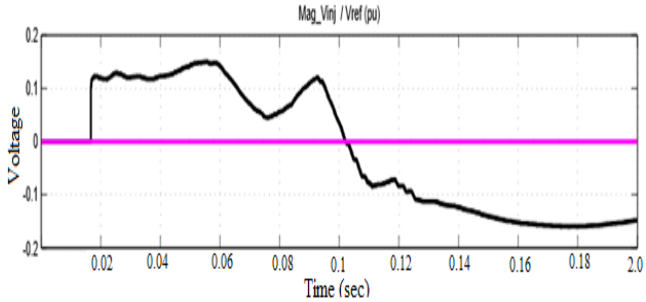


Figure.13b Simulation results of 72-pulse GUPFC series compensator for variation in voltage magnitude of $V_{inj}$ with $V_{ref}$ under voltage swell.

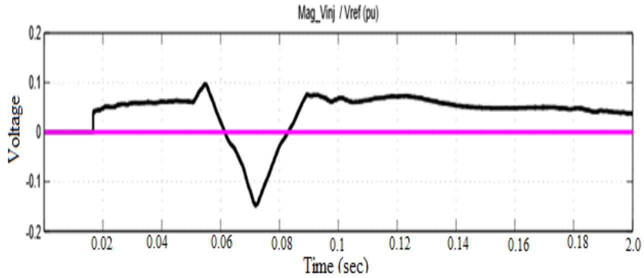


Figure.13c Simulation results of 72-pulse GUPFC series compensator for variation in voltage magnitude of $V_{inj}$ with $V_{ref}$ under interruption.

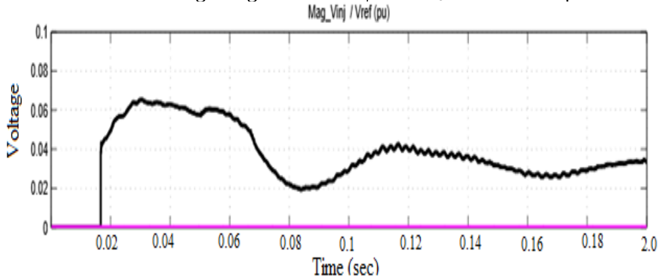


Figure.13d Simulation results of 72-pulse GUPFC series compensator for variation in voltage magnitude of $V_{inj}$ with $V_{ref}$ under transients.

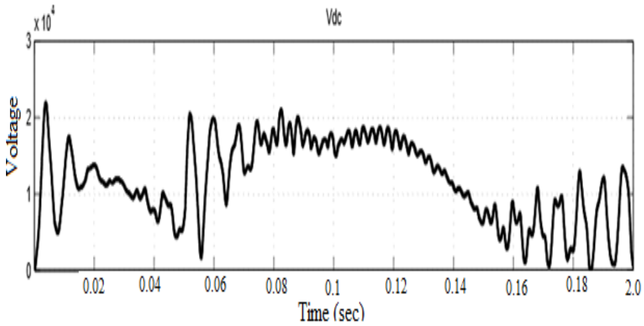


Figure.14a Simulation results of 72-pulse GUPFC series compensator for variation in capacitor voltage under voltage sag.

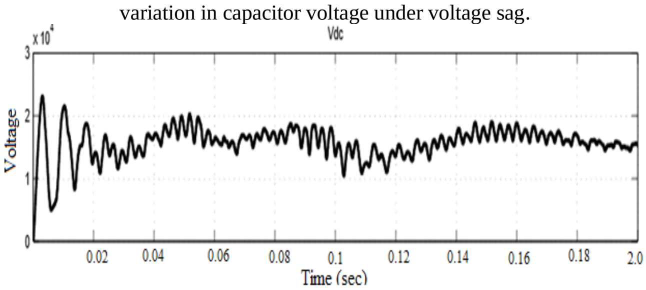


Figure.14b Simulation results of 72-pulse GUPFC series compensator for variation in capacitor voltage under voltage swell.

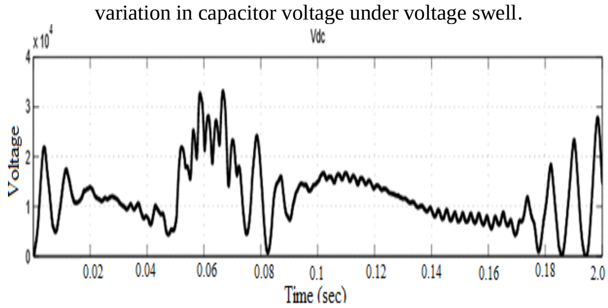


Figure.14c Simulation results of 72-pulse GUPFC series compensator for variation in capacitor voltage under interruption.

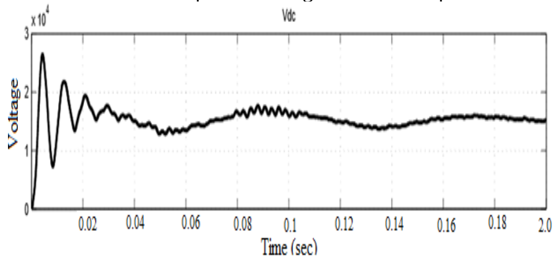


Figure.14d Simulation results of 72-pulse GUPFC series compensator for variation in capacitor voltage under transients.

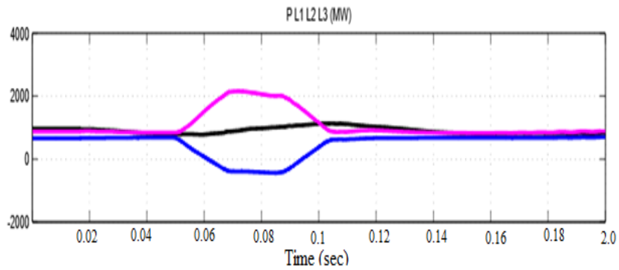


Figure.15a Simulation results of 72-pulse GUPFC series compensator for variation in active power under voltage sag.

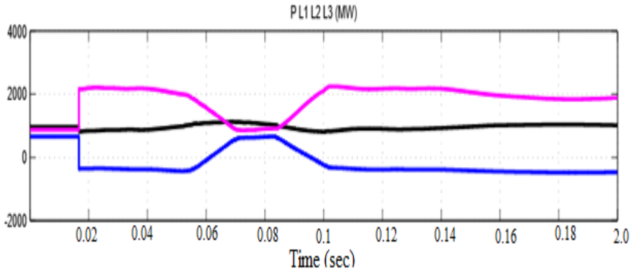



Figure.15b Simulation results of 72-pulse GUPFC series compensator for variation in active power under voltage swell.

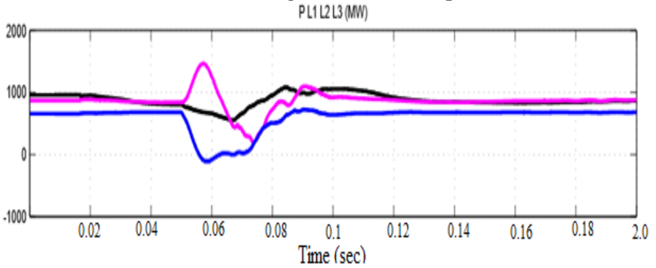



Figure.15c Simulation results of 72-pulse GUPFC series compensator for variation in active power under interruption.

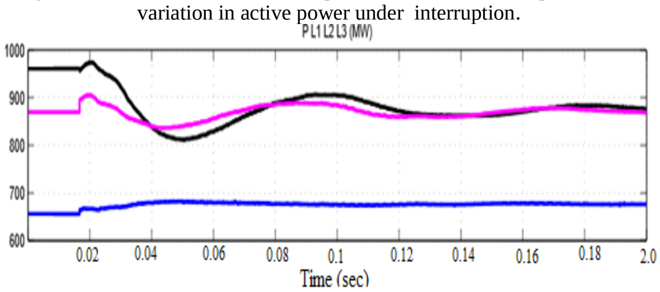



Figure.15d Simulation results of 72-pulse GUPFC series compensator for variation in active power under transients.

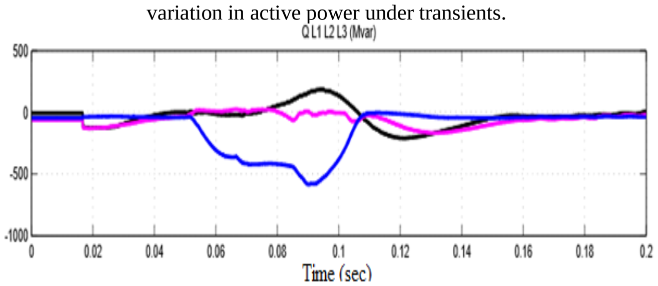



Figure.16a Simulation results of 72-pulse GUPFC series compensator for variation in reactive power under voltage sag.

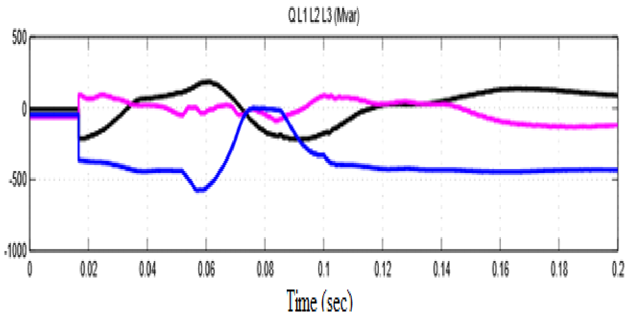



Figure.16b Simulation results of 72-pulse GUPFC series compensator for variation in reactive power under voltage swell.

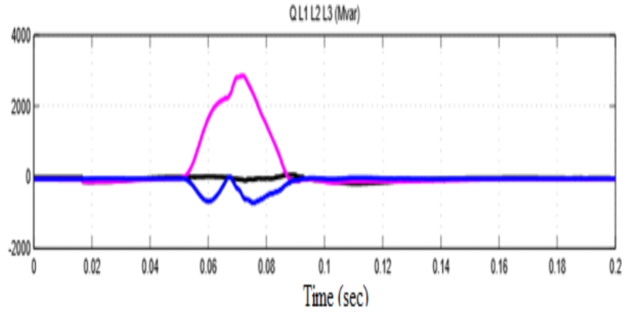



Figure.16c Simulation results of 72-pulse GUPFC series compensator for variation in reactive power interruption.

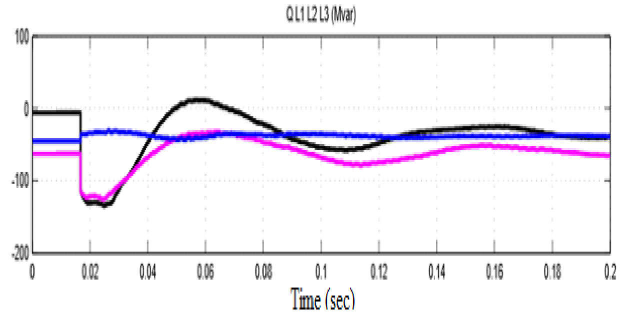



Figure.16d Simulation results of 72-pulse GUPFC series compensator for variation in reactive power under transients

Table 1. Comparative analysis of Total Harmonic Distortion

| Power Quality Problem | Total Harmonic Distortion (%) | | | |
|---|---|---|---|---|
| | Without FACTS device | With 48-pulse GUPFC | With 60-pulse GUPFC | With 72-pulse GUPFC |
| Voltage Sag | 47.47% | 19.22% | 17.72% | 5.59% |
| Voltage Swell | 35.14% | 13.67% | 12.96% | 12.08% |
| Interruption | 41.93% | 41.71% | 40.36% | 37.74% |
| Transients | 6.67% | 6.37% | 5.93% | 5.22% |

## 5. CONCLUSIONS

The increasing complexities of large inter connected networks had fluctuations in reliability of power supply, which resulted in system instability, difficult to control the power flow, existence of voltage sag, voltage swell, interruptions, harmonic distortions, transients and security problems are analysed. The Generalized Unified Power Flow Controller (GUPFC) is a Voltage Source Converter (VSC) based Flexible AC Transmission System (FACTS) controller for shunt and series compensation among the multiline transmission systems is developed using the MATLAB/Simulink. This paper presents the complete digital simulation of the improved configurations of GUPFC within the power system is performed in to handle the power quality issues. The proposed model is tested under various power quality problems and found that increasing the number pulse in voltage source converter based GUPFC can control power quality issues effectively. The paper proposes a full model comprising of voltage source converter based GUPFC is constructed for digital simulation to investigate the performance of the controller on various power quality problems and observed that considerable improvement is identified on 48,60 and 72-pulse Voltage source converter.

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