

A Comparative Study of Transmission Line-Fault Mitigation Under Various Fault Conditions Using Fuzzy Induced- UPQC Controllers

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ABSTRACT

This paper presents a novel approach for mitigating power quality issues in transmission lines using a Unified Power Quality Conditioner (UPQC) equipped with fuzzy logic-based control. Power quality disturbances such as voltage sags, swells, harmonics, and interruptions can significantly affect the performance of sensitive loads and compromise the reliability of the power system. The proposed UPQC system integrates both series and shunt active power filters to compensate for voltage and current disturbances simultaneously, ensuring enhanced power quality. Fuzzy logic control is employed to dynamically adjust the UPQC parameters based on the real-time system conditions, enabling efficient and adaptive performance under various fault scenarios. The design and simulation of the proposed UPQC system are implemented using MATLAB/Simulink software. Extensive simulations are conducted to evaluate the effectiveness of the fuzzy logic-based control strategy in mitigating different types of faults in transmission lines. Simulation results demonstrate significant improvements in power quality, validating the efficacy of the proposed approach. The proposed UPQC design with fuzzy logic control offers a promising solution for enhancing power quality and ensuring the reliable operation of transmission systems in the presence of diverse fault conditions.

Keywords: UPQC, MATLAB/Simulink, Line fault, fuzzy logic controller, Harmonics, THD.

1. INTRODUCTION

The flexible AC transmission systems (FACTS) concept based on applying leading edge Power Electronics Technology to existing AC transmission systems, improves stability to increase usable power transmission capacity to its thermal limit. A UPFC can simultaneously provide control of the transmission line impedance, phase angle and voltage [1].

The UPFC is constructed from two power electronic inverters which are connected together by a common DC link [2]. Two transformers are utilized to detach the UPFC and to match the voltage levels between the power framework and the power electronic inverters. One of the inverters is associated with the transmission line. The series associated inverter can produce a voltage which can have customizable extent and stage point. This inverter consequently can give both genuine and responsive capacity to the transmission line. The subsequent inverter principally gives the genuine power expected by the series inverter yet it can likewise work as a free VAR compensator. Accordingly, the UPFC have some control over the progression of genuine and responsive power in the transmission line [3].

The two VSI's can work autonomously by isolating the DC side. In this way, all things considered, the shunt inverter is working as a STATCOM that produces or retains responsive ability to manage the voltage extent at the interfacing point. The series inverter is working as SSSC that creates or retains responsive ability to direct the ongoing stream, and consequently the power stream on the

transmission line is controlled. The UPFC can be utilized to further develop the power quality because of the different controlling capacity of genuine and responsive power [4].

2. FACTS CONTROLLERS

With the continuous development and development of the electric utility industry, remembering liberation for some nations, various changes are persistently being acquainted with a once unsurprising business. In spite of the fact that power is an exceptionally designed item, it is progressively being thought of and taken care of as a ware. In this way, transmission frameworks are being pushed nearer to their solidness and warm cutoff points while the emphasis on the nature of force conveyed is more noteworthy than any time in recent memory [5].

In the developing utility climate, monetary and market influences are, and will proceed to, request a more ideal and productive activity of the power framework regarding age, transmission, and dissemination. Now, more than ever, advanced technologies are paramount for the reliable and secure operation of power systems. To achieve both operational reliability and financial profitability, it has become clear that more efficient utilization and control of the existing transmission system infrastructure is required. Improved utilization of the existing power system is provided through the application of advanced control technologies. Power electronics-based equipment, or Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new transmission lines [6]. Traditional solutions to upgrade the electrical transmission system infrastructure have been primarily in the form of new transmission lines, substations, and associated equipment. However, as experiences have proven over the past decade or more, the process to permit, site, and construct new transmission lines has become extremely difficult, expensive, time-consuming, and controversial [7].

Realities innovations give progressed arrangements as savvy options in contrast to new transmission

line development. The likely advantages of Realities hardware are currently broadly perceived by the power frameworks designing and T&D people group. As for Realities hardware, voltage obtained converter (VSC) innovation, which uses self-commutated thyristors/semiconductors, has been effectively applied in various establishments around the world [8].

2.1 Power System Constraints

As noted in the introduction, transmission systems are being pushed closer to their stability and thermal limits while the focus on the quality of power delivered is greater than ever. The limitations of the transmission system can take many forms and may involve power transfer between areas (referred to here as transmission bottlenecks) or within a single area or region (referred to here as a regional constraint) and may include one or more of the following characteristics:

- Steady-State Power Transfer Limit
- Voltage Stability Limit
- Dynamic Voltage Limit
- Transient Stability Limit
- Power System Oscillation Damping Limit
- Inadvertent Loop Flow Limit
- Thermal Limit
- Short-Circuit Current Limit
- Others

Each transmission bottleneck or regional constraint may have one or more of these system-level problems. The key to solve these problems in the most cost-effective and coordinated manner is through systems engineering analysis [9].

2.2 Conventional devices For Enhancing Power System Control

- Series Capacitor -Controls impedance
- Switched Shunt Capacitor and Reactor - Controls voltage
- Transformer LTC -Controls voltage
- Phase Shifting Transformer -Controls angle
- Synchronous Condenser -Control Voltage
- Special Stability Controls -Typically focuses on voltages control but can often include direct control of power

3. INTRODUCTION INTELLIGENT CONTROLLER DESIGN FOR UPQC SYSTEM

The digital simulation of the following closed loop schemes has been described in this chapter.

- I. Fuzzy logic converter based UPQC fed power system.
- II. PI controller based UPQC fed power system.
- III. AWPI controller based UPQC fed power system.

The performance of these closed loop schemes has been compared with its counterpart the open loop system. The performance of UPQC mainly depends on how quickly and accurately it does the work of compensation and mitigates the voltage sag and swell. The simulated results demonstrate the effectiveness of fuzzy logic, PI and AWPI controllers in terms of peak overshoot and steady state errors [10].

3.1 Fuzzy Logic Algorithm

The term fuzzy logic inspires certain skepticism, sounding equivalent to "half-baked logic" or "bogus logic". The logic involved can deal with concepts that cannot be expressed as "true" or "false" but rather as "partially true". It is a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively). Fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans [11].

3.2 Fuzzy Logic Controller

The structure of complete fuzzy control system composed of four blocks viz., fuzzification, knowledge base, inference engine and defuzzification. The fuzzification module converts the crisp values of the control inputs into fuzzy values. A fuzzy variable is defined by linguistic variables (fuzzy set or sub sets) such as low (L), Medium (M) and high (H), big (b), zero (Z), slow where each refers to a gradually varying membership function. In fuzzy set terminology, all the possible values that a variable can assume are named universe of discourse and the fuzzy sets

(characterized by membership function) cover whole universe of discourse. The shape of fuzzy sets can be triangular, trapezoidal etc.

3.3 Fuzzy Logic Controller Based UPQC Fed Power System

A UPFC is used with Fuzzy Logic controller to improve the power quality i.e., to reduce the duration of sag, swell and the peak overshoot. The block diagram of FLC is shown in Figure 1. The error between the reference values and the measured system parameters and the rate of change of error (CE) are calculated. These values form the crisp inputs for the Sugeno fuzzy system. The triangular membership functions are used to obtain the fuzzified values from the crisp values, as this membership function is the simplest compared to the other membership functions. The fuzzy inference system, then generates the required switching pulses for the UPFC. Table 1 shows the fuzzy rule base with 4 rules which were designed on the dynamic behavior of signal error and its rate of change. Load 2 is switched on and the time taken for switching the UPFC is approximately 0.01 sec.

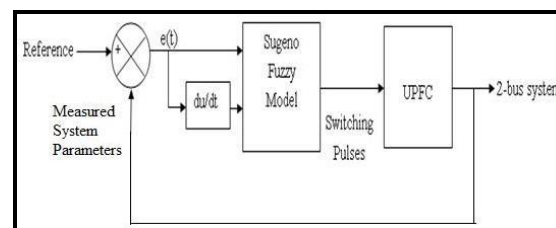


Fig 1: Block Diagram of Fuzzy Based UPQC system

The error between the reference voltage value and the measured voltage and the rate of change of voltage error are fed as input to the fuzzy logic controller. These values are fed as crisp inputs to the fuzzy logic controller and are converted into fuzzy sets by using min-max method. The input functions are framed from the following expressions.

$$\text{Error, } E = e(t) = V_r(t) - V_a(t) \quad (2.1)$$

$$\text{Change in error, CE} = e(t) - e(t-1) \quad (2.2)$$

Where,

V_r = reference voltage in volts

V_a = measured voltage in volts $e(t-1)$ = error at the previous instant

Table 1. Linguistic Rule

Change in Error (CE)	Error (E)	
	L	H
L	Z	M
H	Z	H

Membership function values are assigned to the linguistic variable using two fuzzy subsets viz., L (low) and H (High). The partition of fuzzy subsets and the shape of the membership function adapt the shape of the appropriate system. Table 4.1 depicts the linguistic rule for fuzzifying the input error and change in error values. The IF-THEN rules are framed as follows:

- IF E = L AND CE = L THEN OUTPUT FUZZY SET = Z
- IF E = L AND CE = H THEN OUTPUT FUZZY SET = Z
- IF E = H AND CE = L THEN OUTPUT FUZZY SET = M
- IF E = H AND CE = H THEN OUTPUT FUZZY SET = H

4. SIMULATION MODEL

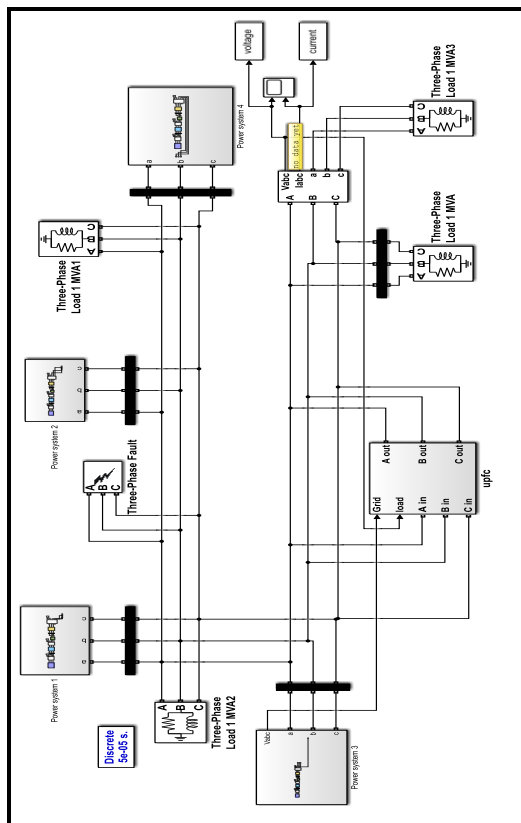


Fig 2: Simulation model of UPFC with fuzzy controller

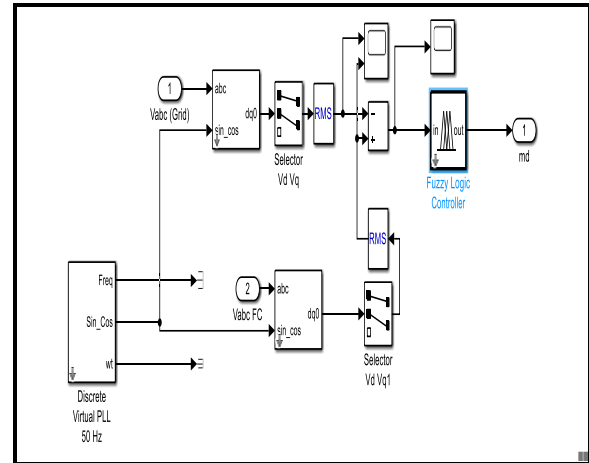


Fig 3: voltage controller for UPFC

The proposed fuzzy based UPFC system is simulated using MATLAB/Simulink. The fuzzy editor, the corresponding fuzzy rule viewer and surface viewer are shown in figures. The two inputs viz., error and change in error are framed using triangular membership functions.

4.1 Simulation results with fuzzy logic controller

Case 1: LLLG fault

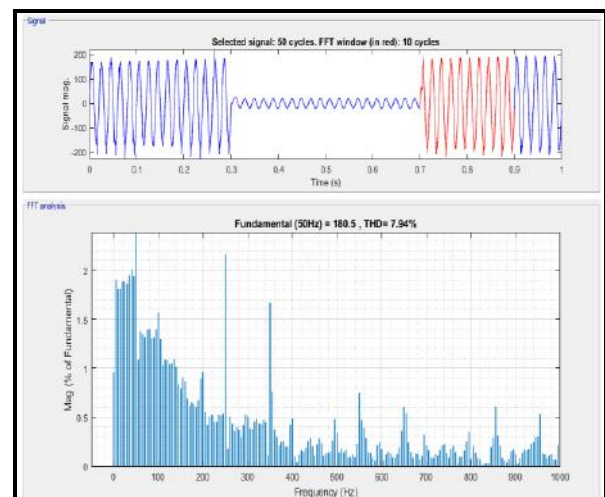


Fig 4: THD for LLLG fault with fuzzy controller

Case 2: LLL fault

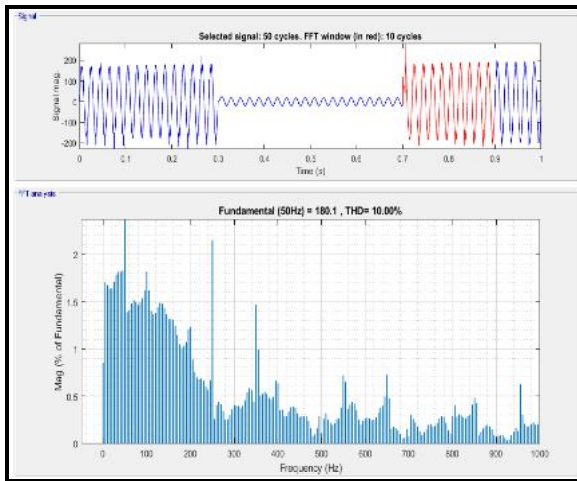


Fig 5: THD for LLL fault with fuzzy controller

Case 3: LLG fault

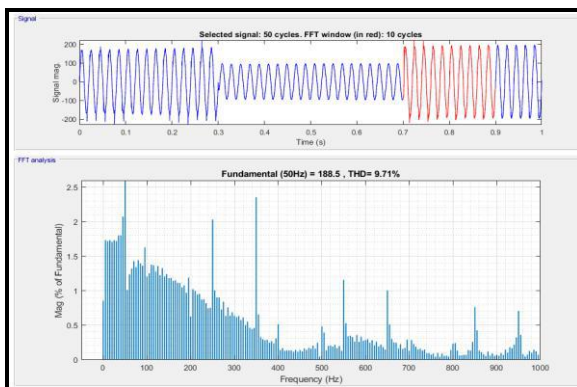


Fig 6: THD for LLG fault with fuzzy controller

Case 4: LL fault

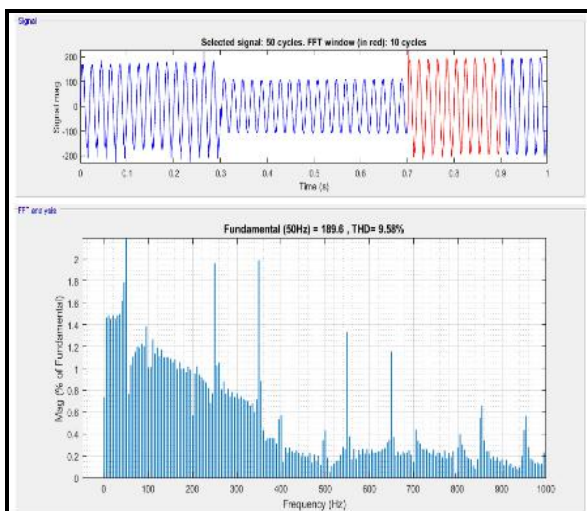


Fig 7: THD for LL fault with fuzzy controller

Case 5: LG fault

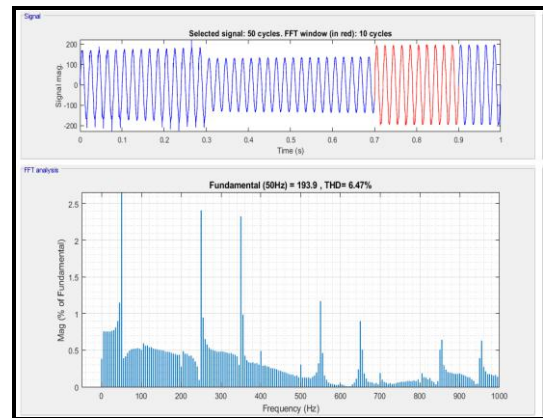


Fig 8: THD for LG fault with fuzzy controller

4.2 Simulation results without controller

Case 1: LLLG fault

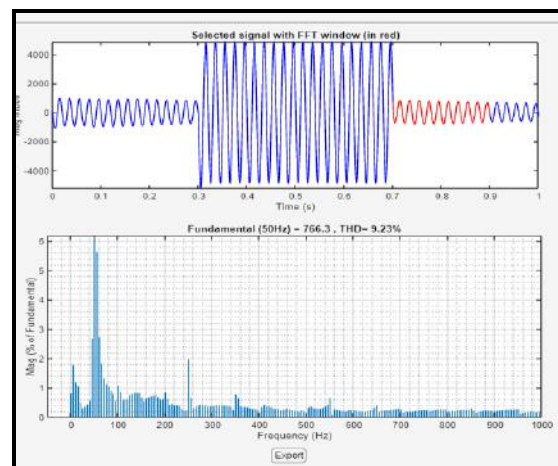


Fig 9: THD for LLLG fault

Case 2: LLL fault

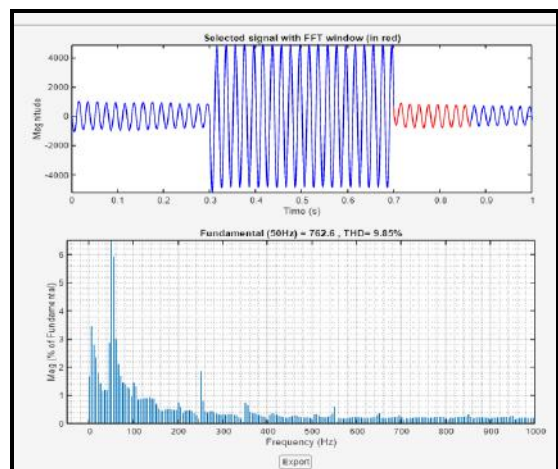


Fig 10: THD for LLL fault

Case 3: LLG fault

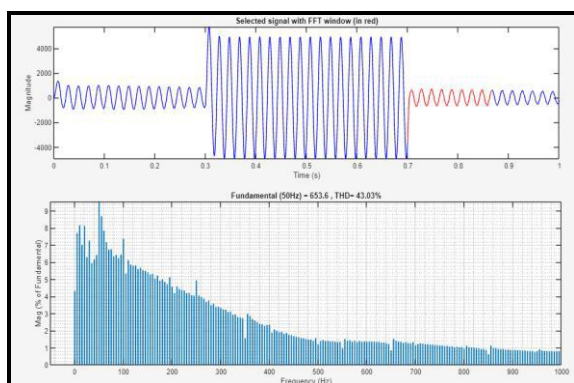


Fig 11: THD for LLG fault

Case 4: LL fault

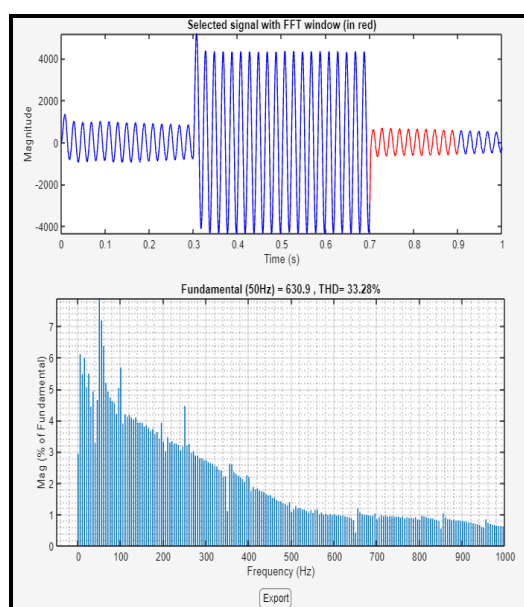


Fig 12: THD for LL fault

Case 5: LG fault

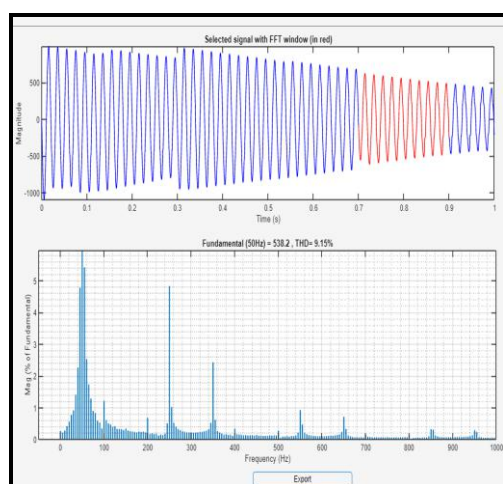


Fig 13: THD for LG fault

5. CONCLUSION

Voltage sags and current harmonics are the most important power quality problems in commercial and industrial utility's customers. These power quality problems can cause tripping of sensitive electronic equipment's, abnormal operations of facilities and tremendous economic losses. This work describes an improved control strategy called FLC for the operation of UPQC system. The UPQC model is simulated in MATLAB using instantaneous power theory. The system is tested under five different line fault conditions and THD is measured in each case. Table 2 shows results obtained after each simulation.

Table 2. Result summary

Type of Fault	Without UPQC THD	With UPQC - THD
LLLG fault	9.23%	7.94 %
LLL fault	9.85 %	10 %
LLG fault	43.03 %	9.71 %
LL fault	33.28 %	9.58 %
LG fault	9.15 %	6.47 %

Hereby we can see that the Compensating strategies have improved the power capability of system. Further the current harmonics in this thesis work has been relatively reduced to the THD level 6.47%. As a conclusion, objectives have been achieved with a chosen different fault conditions with the effect on the grid connected system.

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