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Mitigation of Harmonics by Fuzzy logic controlled Series Compensator

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Abstract: *In this paper, series compensator is proposed to reduce the harmonic distortion in the sensitive load due to the presence of non linear loads in the power system network. The series compensation method is best suited to protect such load against this disturbance. The use of a series compensator (SC) to improve power quality is an isolated power system is investigated. In this paper, a series compensator is proposed and a method of harmonic compensation is described using PI controller and Fuzzy controller. The proposed series compensator consists of Energy Storage System (ESS) and Voltage Source Inverter (VSI), Injection Transformer. The ESS can be a capacitor of suitable capacity. ESS would act as a buffer. Injection Transformer is used to inject the voltage in transmission line in appropriate level. In this way the terminal voltage of the protected sensitive load can be regulated to maintain a constant level. The modeling and simulation of the proposed series compensator was implemented in Matlab Simulink work space. Simulation results showed that the proposed series compensator was efficient in mitigating harmonics and compare with the both controllers and thus improve the power quality of the isolated power system. This approach is different from conventional methods and provides effective solution. If this method is enhanced in future it could provide much more improved power quality.*

Keywords: Power Quality Problem; Fuzzy Logic Controller, Series Compensator; ESS; VSI; Harmonics; MATLAB.

I. INTRODUCTION

Isolated power systems are commonly found in rural and remote areas of the world. Isolated power systems are characterized by limiting generating capacity. The sensitive loads which are present in the isolated power systems are much more affected by the power quality problems. Power Electronics and Advanced Control technologies have made it possible to mitigate power quality problems and maintain the operation of sensitive loads. Power quality problems encompass a wide range of disturbances such as voltage sags/swells, flickers, harmonics distortion, impulse transient, and interruptions.

Among power system disturbances, harmonics are severe problems to the sensitive loads, because, the occurrence of harmonics in the system can cause excessive losses and heating in motors, capacitors and transformers connected to the system. To avoid those undesirable affects the proposed method mitigates the problems caused by harmonics.

This paper analyses the key issues in the power quality problems, harmonics occurs due to the connection of controlled six pulse converter (rectifier) to the main drive load(non linear load). All these factors affect the sensitive load which is connected in parallel to the main drive load. To achieve the challenges in maintaining power quality the proposed method to use Series Compensator with PI controller and Fuzzy controller to mitigate the harmonics. A comprehensive of proposed system with controllers have been carried out in MATLAB environment using Simulink. In this work, comparative study of these controllers has also been made.

II. MAIN SOURCES, CAUSES AND EFFECTS OF HARMONICS

Power Quality is “Any power problem manifested in voltage, current, or frequency deviations that results in failure or misoperation of customer equipments”[1]. Power systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency. However, in practice, power systems, especially the isolated systems, some of the primary source of distortion can be identified as below[2].

- Non – Linear Loads
- Power Electronic Devices
- IT and Office Equipments
- Arcing Devices
- Load Switching
- Large Motor Starting
- Electromagnetic radiations and Cables

While power disturbances occur on all electrical systems, the sensitivity of today’s sophisticated electronic devices makes them more susceptible to the quality of power supply. For some sensitive devices, a momentary disturbance can cause scrambled data, interrupted communications, a frozen mouse, system crashes and equipment failure etc. A power voltage spike can damage valuable components. Power quality encompasses harmonics distortion produces. The causes are,

1. Electromagnetic interference from appliances, machines, radio and TV broadcasts.
2. Harmonic distortion from nonlinear loads (computers, lights)

The effects are,

1. Continuous distortion of normal voltage
2. Random data errors

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III.METHODS TO IMPROVE POWER QUALITY ISSUES

A traditional method to achieve improve power quality is to use passive filters connected at the sensitive load terminals. However, this practice has some shortcomings: the effectiveness of the scheme could deteriorate as the source impedance or load condition changes; it can lead to resonance between the filter and the source impedance. Essentially an active filter, connected at the sensitive load terminal, injects harmonic currents of the same magnitude but of opposite polarity to cancel the harmonics present there [3]. Thus, the challenge is to regulate the sensitive load terminal voltage so that its magnitude remains constant and any harmonic distortions are reduced to an acceptable level. This paper introduces series compensator and its operating principle. Then a simple control based PI and Fuzzy Logic Controller based PWM method is used to compensate Harmonics. At the end MATLAB SIMULINK model based simulated results were presented to validate the effectiveness of the proposed control method of Series Compensation.

IV. MODELLING OF SERIES COMPENSATOR

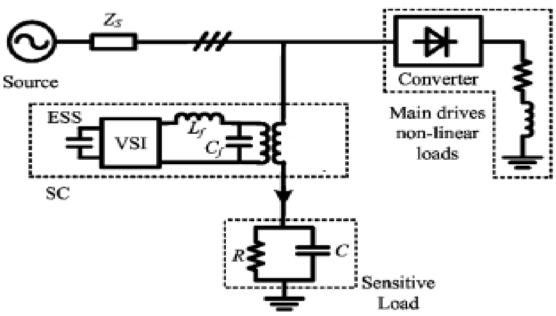


Figure 1. The basic structure of Series Compensator

The simple power system model shown in Figure 1 is used to explain the principle of the proposed mitigation method [4]. The upstream generators are aggregated and represented as an ideal voltage source. Z_s represents the equivalent source impedance. The main drives or machinery loads are modeled as a lumped resistive-inductive load connected to the source through a power converter, assumed to be a six-pulse rectifier. The much smaller capacity sensitive loads are assumed to be supplied through point of common coupling and are modeled by the resistor R in parallel with the capacitor C. The SC is connected upstream from the sensitive load through an injection transformer. It is series connected with the sensitive load. The function of the SC is to ensure that the voltage across the sensitive load terminals is of high quality. The central part of the SC is an energy storage system (ESS) and a VSI where a PI and FL controller based PWM switching scheme is often used [5]. The ESS can be a capacitor of suitable capacity. Because of the switching action of VSI, harmonics are generated, this harmonics are filtering is required for suitable LC filter is used.

V.CONTROL PHILOSOPHY USED IN SERIES COMPENSATOR

The harmonics is generated in the load terminals using six pulse converter with fixed firing angle 30 degree and this is connected to the main drive non linear load which is parallel to the sensitive load.The following figure 2 shows the control block of the SC.

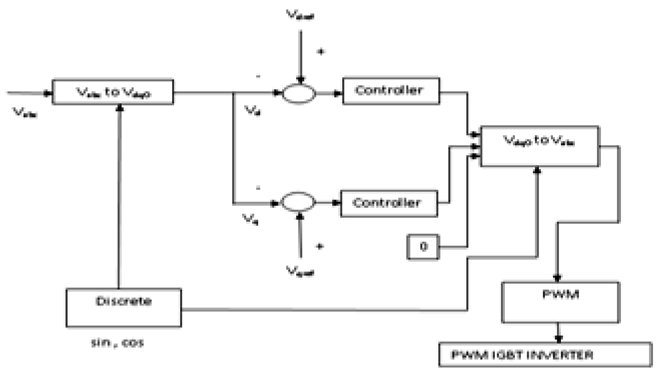


Figure 2. Block diagram of Control Unit

Harmonic voltage problems like fundamental plus harmonics components are sensed separately and passed through the V_{abc} to V_{dq0} transformation block. This block performs the abc to dq0 transformation on a set of three-phase signals[6] . It computes the direct axis V_d, quadratic axis V_q, and zero sequence V_0 quantities in a two axis rotating reference frame according to the following transformation of the following equations 1.2.3.

$V_d=2/3*[V_a*\sin(wt)+V_b*\sin(wt-2pi/3)+V_c*\sin(wt+2pi/3)]$ ...(1)

$V_q=2/3*[V_a*\cos(wt)+V_b*\cos(wt-2pi/3)+V_c*\cos(wt+2pi/3)]$...(2)

$V_0=1/3*[V_a + V_b + V_c]=0$ ...(3)

For simplicity zero phase sequence components is ignored. The dq method gives the voltage depth (d) and phase shift (q) information with start and end times. After conversion, the three-phase voltage V_a, V_b and V_c become two constant voltages V_d, V_q.

This V_d, V_q voltage is summed with V_d, V_q references which in turn converted to dq steady state error. They are easily controlled by controllers (PI and FL Controllers). After that the output of the controllers is given to the V_{dq0} to V_{abc} transformation block. This block transforms three quantities (direct axis, quadature axis and zero-sequence components) expressed in a two axis reference frame back to phase quantities according to the following transformation of the following equations 4,5,6.

$V_a = [V_d*\sin(wt) + V_q*\cos(wt) + V_o]$ ...(4)

$V_b = [V_d*\sin(wt-2pi/3) + V_q*\cos(wt-2pi/3) + V_o)]$ ...(5)

$V_c = [V_d*\sin(wt+2pi/3) + V_q*\cos(wt+2pi/3) + V_o)]$ ...(6)

After conversion, the V_d, V_q and V_0 become three phase voltages V_a, V_b and V_c. Finally this signal is given to the PWM generator as the input to produce required firing signals for each leg of the PWM inverter. The control method should not be affected from the harmonics correct detection of the phase of the source voltage is very important for SC. Using a Phase Locked Loop (PLL) satisfies these requirements [7]. The carrier frequency used for the PWM generator is 10khz. In this papar investigation, Series Compensator has been realized by means of two types of controllers – Proportional Integralcontroller (PI) and Fuzzy Logic controller (FL).

VI. ILLUSTRATION OF THE SERIES COMPENSATOR SYSTEM

The parameters for the proposed system are given in Table 2. It is used to verify the effectiveness of the Series Compensator with Fuzzy controllers. The simulations were accomplished using Matlab simulink.

TABLE 2. System Parameters

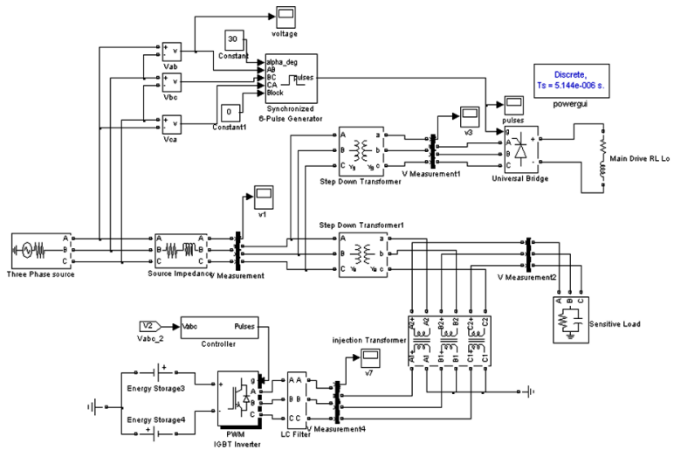
SI.No	Parameters	Values used in the Simulation Models
1	Main supply voltage per phase	380 V
2	Line Frequency	50 Hz
3	Source Impedance	Ls = 0.005 mH Rs = 0.001Ω
4	Injection transformer turn ratio	1:1
5	PI controllers	**Controller d** Kp = 40 Ki = 154 Sample time=5 µs **Controller q** Kp = 25 Ki = 260 Sample time = 5 µs

VII.SIMULATION RESULTS AND DISCUSSIONS

Harmonic Generation and mitigation of harmonics using Fuzzy Logic Controller

In the proposed system, the first simulation carried out, the harmonics is generated in the transmission line using six pulse converter connected to the main drive non linear load which is parallel to the sensitive load. Matlab simulation carried out **without compensation technique**.

The percentage of total harmonic distortion in the sensitive load side is, in phase1 18.17%, in phase2 20.01%, in phase3 19.78%. The Matlab simulation carried out **with compensation technique using Fuzzy logic controller**. The percentage of total harmonic distortion in the sensitive load side is, in phase1 3.59%, in phase2 7.21%, in phase3 6.13%.



Simulink Model

VIII.RESULTS AND DISCUSSIONS

The following tables show the simulation result carried out with and without using series compensator in mitigating harmonics

TABLE 3. Matab Simulink Results for Harmonics

Phases	Sensitive Load- Before Compensation THD IN %	Sensitive Load – After Compensation Using Fuzzy Logic Controller THD IN %
Phase 1	18.17	3.59
Phase 2	20.01	7.21
Phase 3	19.78	6.13

A thyristor based six pulse converter used in this system is a power electronic device (fast switching device) adds harmonics in the system voltage and increases the total harmonics distortion of the system. The table 3 shows simulation results carried out for hamonics without using series compensator and with series compensator using PI and Fuzzy controllers respectively.

When the system simulation is carried on without series compensator the harmonics are generated at load point of all three phases. This harmonics affects the sensitive load. Then the series compensator is brought in to service for harmonic mitigation, the sensitive load is protected against the distortion introduced by the main drive load and the total harmonic distortion is reduced up to 63% by using PI controller and 64% by using Fuzzy logic controller as shown in table 3. These approaches help to mitigate harmonics better when compared to other traditional methods. The above tabular column also shows that the Fuzzy controller mitigates harmonics better than PI controller.

IX.CONCLUSION

Voltage quality improvements in an isolated power system through series compensation technique using PI and Fuzzy logic controllers have been investigated. The power system contains significant proportion of fluctuating nonlinear load and a high level of harmonic distortions is observed. A method to control the injection voltage of the SC so that it can mitigate the effects of the harmonics has been proposed. The SC is also designed to maintain the fundamental frequency component of the terminal voltage of protected sensitive load.

In this paper, a complete simulated series compensator system with PI and Fuzzy logic controllers have been developed by using matlab simulink software. It is shown that the simulated SC with both controllers developed works successfully without lacks in its performance. The proposed SC with both the controllers helps to improve power quality.

The proposed system with both the controllers will work better than the traditional methods of mitigating harmonics. The proposed SC with Fuzzy logic controller can handle both balanced and unbalanced situations without any difficulties and would inject the appropriate voltage component to correct rapidly and anomaly in the supply voltage to keep the load voltage balanced and constant at the nominal value.

In this paper, comparative study of these controllers has also been made. The result of the work shows that the Fuzzy controller mitigates harmonics slightly better than PI controller.

X.SCOPE OF THE FUTURE WORK

If the proposed system is enhanced it could mitigate all other power quality problems that can occur in power systems and also, if the control scheme is improved using artificial Neural network then the harmonics problem can be further minimized.

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