ISSN (Online) 2321-2004
ISSN (Print) 2321-5526
INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 3, Issue 6, June 2015

Power Quality Improvement by Fuzzy Logic based Series Active Power Filter

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Abstract: Power quality (PQ) is one of the most important issues of modern electrical distribution. The series active filter can play a very significant role in the correction of PQ problems such as voltage unbalance, sag, interruption. This paper deals with the determination of voltage references for series active power filter based on a robust three-phase digital locked loop (PLL) system. Fuzzy logic controller is studied and in order to assure good reliability. The robustness of the regulators allows the PLL operating under non ideal conditions and provides good results under unbalanced and/or distorted supply voltages conditions. Simulation results are presented to confirm the validity of the proposed design.

Index Terms: Power Quality, Series Active Power Filter, Fuzzy Logic Control

I. INTRODUCTION

Any problem manifested in, current or frequency, voltage deviation that results in failure of customer equipment is known as power quality problem. The lack of quality can cause loss of production, damage to equipment and human health. Therefore it is obvious to maintain high standards of power quality. The power quality problems are voltage sag, distortion, voltage swell, harmonics etc. [1,2]
The IEC (International Electro Technical Committee) has defined power quality disturbances have been classified into seven categories based on wave shape.[1]
Various power quality problems are classified as below.

1. Transient
Transient is that part of the change in a voltage or current that disappears during transition from one steady state operating Condition to the other.
The Transient problem is further classified into two different types on basis of wave shape.
a. Impulsive
An impulsive transient is a sudden; non–power frequency change in the steady-state
Condition of voltage, current, or both that is unidirectional in polarity (which is either positive or negative).
Impulsive transients are normally characterized by their rise and decay times.
b. Oscillatory
An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values.

2. Long duration & short duration problems
a. Long duration problems
When rms voltage deviations at power frequency last longer than one minute, is classified as long duration voltage variations.
Interruption and cut of the power to the customer, for particular time duration, is considered as the long duration problems.
b. Short duration variations
The voltage variation at power frequency shorter than one minute is defined as short duration variation. The short duration voltage variations can be either voltage dips (sags) or voltage rises (swells). [2] Sag is a decrease of rms voltage to a value between 0.1 and 0.9 p.u. from 0.5 cycle to 1 minute. [1]
A voltage swell is an increase of rms voltage to a value between 1.1 and 1.8 p.u. at the power frequency from 0.5 cycles to 1 minute. [1]
Flicker is a change in magnitude of the voltage or frequency at such a rate to be perceptible to the human eye.

3. Waveform distortion
a. D.C offset
The presence of DC voltage or current in AC power systems is termed as DC offset.
b. Harmonics
Voltages or currents having frequency components that are integer multiples of the supply frequency are called harmonics.

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Vol. 3, Issue 6, June 2015

c. Inter harmonics

Voltages or currents having frequency components that are not integer multiples of the supply frequency are called inter harmonics.

The section II explains the operational block diagram of Series Active Power Filter and calculation procedure of reference signal.Section III explains the problem formulation of voltage sag in MATLAB Simulink and its mitigation procedure by Series Active Power Filter.

The operation of fuzzy logic controller to generate the gate pulses is also explained in Section III. Section IV shows the results of load voltages before and after employing the Series Active Power Filter. Section V explains the conclusion of the work carried out in this paper and its limitations.

II. SERIES ACTIVE POWER FILTER

The function of series active power filter is to compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell and flicker. [3,4]

The series active power filter compares the positive sequence component with the actual line voltages and calculates the reference value to be injected by the series active power filter.

The calculation procedure is shown in Fig.1

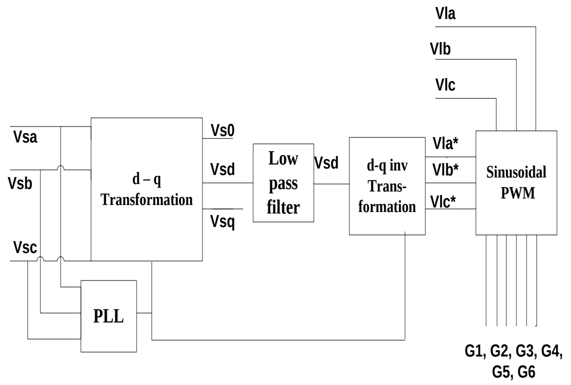

fig. 1. Series Active Power Filter Reference Voltage Signal Generation Diagram [3]

For the reference signal generation, synchronous reference frame is applied to the supply voltage. The three phase supply voltages are transformed in d-q-0 components. The transformation matrix is given in Equation (i)

$$\begin{bmatrix} Vsd \\ Vsq \\ Vs0 \end{bmatrix} = 2/3 \begin{bmatrix} 1/2 & 1/2 & 1/2 \\ sin(wt) & sin(wt - \frac{2\Pi}{3}) & sin(wt + \frac{2\Pi}{3}) \\ cos(wt) & cos(wt - \frac{2\Pi}{3}) & cos(wt + \frac{2\Pi}{3}) \end{bmatrix} \begin{bmatrix} Vsa \\ Vsb \\ Vsc \end{bmatrix} \quad ....(i)$$

For this transformation, the speed of synchronous reference frame (w) is required. This can be derived by PLL (Phase Locked Loop). The Voltage in d axes (V_{Sd}) is combination of average ($\bar{V}sd$) and oscillating ($\tilde{V}_{Sd}$) components of source Voltages.

The average Voltage ($\bar{V}sd$) is calculated by second order low pass filter. The load side reference voltages are calculated by d-q-0 to a-b-c transformation (Inverse d-q transformation). By comparing the reference voltages and load voltages, the error in each phase voltage is calculated and processed by sinusoidal PWM to generate the switching signals for series active filter. [3]

III. SIMULATION

As shown in the fig. 2 three phase voltage supply of 400 V (line to line) is connected to 3kW load and the voltage sag and interruption (power quality problems) are simulated by LLLG fault by changing the value of fault resistance. The time interval for fault is 0.06 to 0.14s. The three phase source voltage is converted in per unit and transferred into d-q-0 from a-b-c to detect the time interval of power quality problems. From the above procedure voltage references VPLLa, VPLLb, VPLLc of each phase is defined.

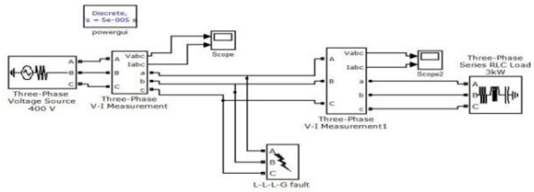

fig. 2. Problem Simulation

To mitigate the Voltage Sag, the Value of sag in voltage and time interval of fault is detected. Reference Value of the voltage is defined and gate pulses for inverter operation are simulated.

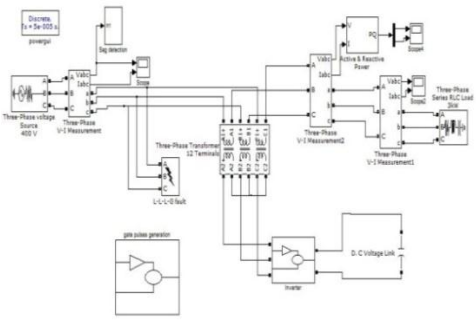

fig. 3. Simulink Model to Mitigate Voltage Sag

Voltage Sag Detection

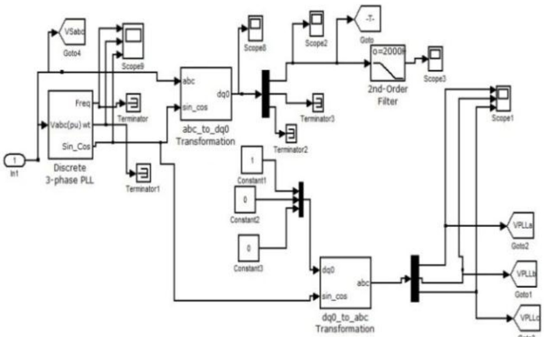

Fig.4. PLL and Voltage Sag Detection Subsystem

The reference voltage and the actual voltages of each phase are compared to get the error in phase voltage. The error andchange in error are given to the fuzzy logic

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Vol. 3, Issue 6, June 2015

controller to get the precise control signal for the gate pulse generation.

Fuzzy Logic Controller Voltage Sag Mitigation

Series Active Power Filter based on the fuzzy logic is more effective compared to the conventional control strategy. [4, 5, 6]The error and change in error in phase voltages are the two inputs for the fuzzy logic controller. To make the fuzzy logic implication voltage is taken in to per unit. [7]The accuracy of the fuzzy logic depends upon the number of membership function and the rules defined for the fuzzy logic Implication. [8] The error in the voltage of each phase and change in the error in the voltage of each phase are separated into seven membership functions. Based on that, 49 linguistic rules are defined for the fuzzy logic implication. The error and change in error are separated in seven membership function as listed below.

LP – Large Positive, MP – Medium Positive, SP – Small Positive, S – Small, SN – Small Negative, MN – Medium Negative, LN – Large NegativeThe control signal or output of fuzzy logic controller is also separated in seven different membership function as listed below.PB – Positive Big, PM – Positive Medium, PS – Positive Small, Z – Zero , NS – Negative Small, NM – Negative Medium , NB – Negative BigThe control signals are used in the sinusoidal PWM technique to generate the gate pulses for the inverter of the series active power filter. The Voltage generated by inverter is given to the system at the timeof Voltage sag and Interruption (Power Quality Problems) via series transformer.

The system parameters for MATLAB Simulink model are as below:

Table I

Parameters	Value
Supply Voltage	400 V (line to line)
Load	3kW
Three Phase Transformer	230/230
Carrier Frequency	5kHz
Inverter Filter	L = 70mH , C = 80μF

The fuzzy logic based gate pulse generation subsystem and inputs and outputs are given below.

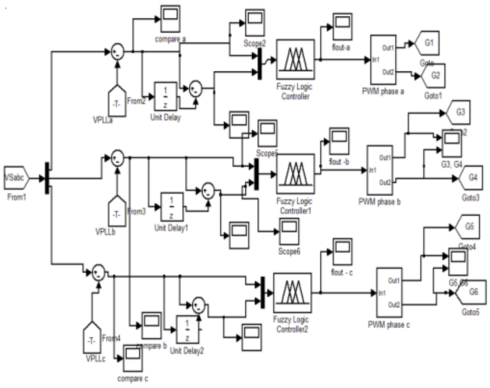

fig. 5. Gate Pulse Generation Subsystem

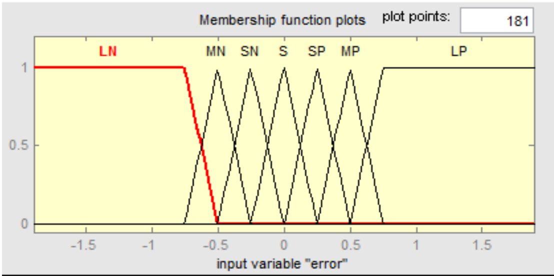

fig. 6. Membership Function for Error

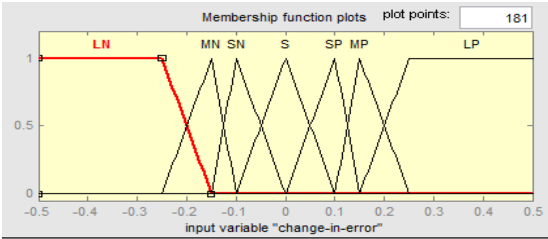

fig. 7. Membership Function for Change in Error

If error is Large Positive and change in error is Large Positive then output is Positive Big. Based on the above Fuzzy Logic Decision Table 49 Linguistic rules are defined.

Table II
Fuzzy Logic Decision Table

Error / Change in Error	LP	MP	SP	S	SN	MN	LN
LP	PB	PB	PB	PM	PM	PS	NS
MP	PB	PB	PM	PM	PS	Z	NS
SP	PB	PM	PM	PS	Z	NS	NM
S	PM	PM	PS	Z	NS	NM	NM
SN	PM	PS	Z	NS	NM	NM	NB
MN	PS	Z	NS	NM	NM	NB	NB
LN	Z	NS	NM	NM	NB	NB	NB

IV. RESULTS & DISCUSSION

L-L-L-G fault is simulated on the system given in fig.2. Change in the fault resistance value creates voltage sag at different value. When the value of the fault resistance is taken as 0.1Ω, the voltage sag in the system voltage is from 1 p.uto 0.6 p.u for the interval of 0.06s to 0.14s. Load voltage waveform is given in fig.8

By series Active Power filter, the Voltage sag is eliminated from the system, but at the time of the starting and ending of the fault the voltage waveform gets distorted as shown in fig.9

DOI10.17148/IJIREEICE.2015.3627

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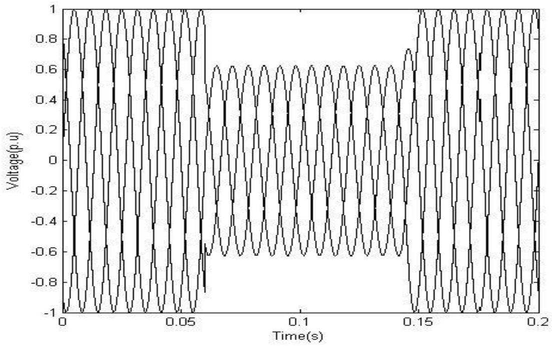

fig. 8. Load Voltage(without Series Active Power Filter)

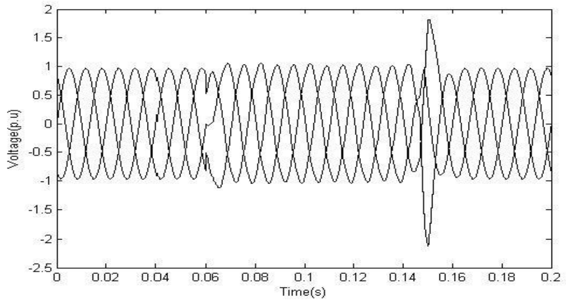

fig. 9. Load Voltage(with Series Active Power Filter)

When the value of the fault resistance is taken as 0.01Ω, the voltage sag in the system voltage is from 1 p.uto 0.1 p.u for the interval of 0.06s to 0.14s. Load voltage waveform is given in fig.10

By series Active Power filter, the Voltage sag is eliminated from the system, but at the time of the starting and ending of the fault the voltage waveform gets distorted as shown in fig. 11

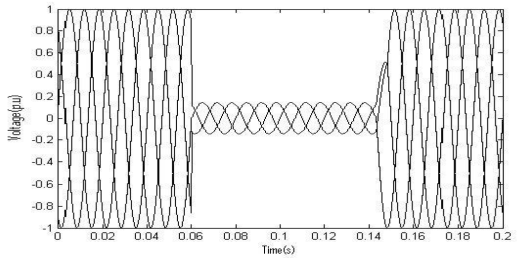

fig. 10. Load Voltage(without Series Active Power Filter)

When the value of the fault resistance is taken much small, the voltage interruption occurs in the system voltage for the interval of 0.06s to 0.14s. Load voltage waveform is given in fig.12

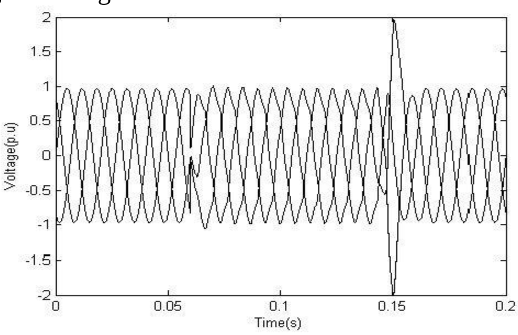

fig. 11. Load Voltage(with Series Active Power filter**)**

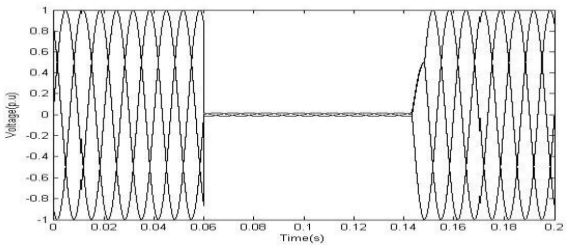

fig. 12. Load Voltage(without Series Active Power filter)

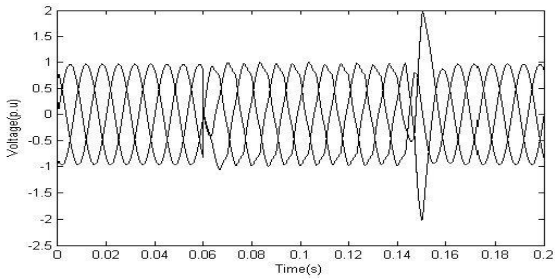

fig. 13. Load Voltage(with Series Active Power filter)

By series Active Power filter, the Voltage interruption is eliminated from the system, but at the time of the starting and ending of the fault the voltage waveform gets distorted as shown in fig.13

V. CONCLUSION

The work done in this paper is related to the study of power quality problems and its compensation with Series Active Power Filter. The Voltage sag and Interruption are taken as power quality problem and simulated in MATLAB Simulink. Fuzzy logic based Series Active Power filter is implemented on system to mitigate the power quality problems. From this, it is clear that voltage sag and voltage interruption are mitigated by the fuzzy based Series Active power filter. But at the time of the starting and ending the waveform gets distorted.

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