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Power Quality Control in Three Phase Four Wire System by Using PR Controller

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Abstract – This paper presents improvement of power quality in three phase four system by using Proportional resonant (PR) controller. Selective harmonic compensation is possible with PR controller because it provide gain at a certain frequency and almost no gain exits at the other frequency. Three phase four wire distribution system are very common and widely used in commercial and industrial installations and therefore power system harmonics in this area take a more attention. In a linear system the characteristic of the voltage and current are sinusoidal in nature. The current contain only one frequency, the main frequency or the so called fundamental frequency. Beside this 60 Hz component there are no other frequencies and therefore there are no harmonic component .On the other hand non linear load changes the sinusoidal nature of the Ac power current, resulting in the flow of harmonic current in the A.c power system. Harmonics are the current or voltages with frequencies that are integer multiple of the fundamental power frequency. Different current controller are used to remove these harmonics .In this paper we use Proportional Resonant (PR) controller which is used in current control for grid control applications where the requirement are to synchronize the current with the constant grid frequency and compensate for the low harmonics . MATLAB/SIMULINK has been employed for presenting the simulation results because it is well established and recognized simulation software for the power system.

Index Terms – PR(proportional resonant) controller, Phase locked loop(PLL),Voltage source inverter(VSI),Pulse width modulator(PWM)

1. INTRODUCTION

Power quality has assumed increasing importance in view of the widespread use of non linear load and power electronics equipment. Further with the deregulation of power industry, competitive pressures force electric utilities to cut costs, which sometimes affect power quality and reliability. Hence it must be ensured by suitable regulations that customers do not suffer from reduced power quality and reliability.[2]

The ultimate reason that we are interested in power quality is economic value. There are economic effect on utilities, their customers, and distributors of load equipment. The quality of power can have a direct economic effect on many industrial consumers. There is big money associated with these disturbances. It is not uncommon for a single, common place, momentary utility breaker operation to result in huge loss to an average-sized industrial concern by shutting down a production line take large time to restart. In the manufacturing industry, the economic effect associated with equipment sensitivity to momentary voltage sags resulted in the development of a whole new standard for equipment ride-through.[4]

The electric utility is concerned about power quality issues as well. Meeting customer expectations and maintaining customer confidence are strong actuator. The loss of a dissatisfied customer to a competing power supplier can have a very significant impact financially on a utility.[1]

Three phase four wire distribution system are very common and widely used in commercial and industrial installations and therefore power system harmonics in this area is required to mitigate. In a linear system the characteristic of the voltage and current are sinusoidal in nature. The current contain only one frequency, the main frequency or the so called fundamental frequency. Beside this 60 Hz component there are no other frequencies and therefore there are no harmonic component .On the other hand non linear load changes the sinusoidal nature of the Ac power current, resulting in the flow of harmonic current in the A.c power system. [3]

In this paper we take short circuit condition to produce harmonic in the Power system and give the timing to the circuit breaker which is connected to the system which is triped after given time which also results generation of harmonic current. In this paper we use PR controller which is used in current control for grid control applications where the requirement are to synchronize the current with the constant grid frequency and compensate for the low harmonic And compare this result with the system without PR controller by using matlab/simulink for presentation of result.

2. PR CONTROLLER

The PR current control strategy is represented by figure1. Ii is the inverter output current which is used as feedback, Ii* is the inverter current reference and Ui* is the inverter voltage reference

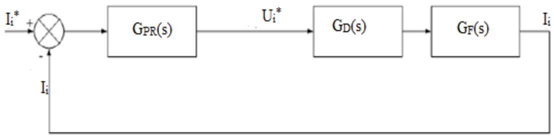

Fig 1: PR Current Control

The PR current controller $G_{PR}(s)$ is represented by:

$$G_{PR}(S) = K_P + K_I \frac{S}{S^2 + \omega_0^2}$$

Where,

KP is the Proportional Gain term,

KI is the Integral Gain term and

ω0 is the resonant frequency.

The ideal resonant term possess in the PR controller offer an infinite gain at the ac frequency ω0 and no phase shift and gain at the other frequencies. The KP term decide the dynamics of the system; bandwidth, phase and gain margins [5][6].

An above Equation represents an ideal PR controller which can give stability problems because of the infinite gain. To remove these problems, the PR controller can be prepared non-ideal by introducing damping as shown in following equation.

$$G_{PR}(S) = K_P + K_I \frac{2\omega_C S}{S^2 + 2\omega_C S + \omega_0^2}$$

Where,

ωc is the bandwidth around the ac frequency of ω0.

The gain of the PR controller at the ac frequency ω0 is now finite but it is still huge enough to generate only a very small steady state error. This equation also makes the controller more easily reliable in digital systems due to their finite precision [5][6].

3. EQUIVALENT CIRCUIT DIAGRAM OF OVERALL CONTROL SYSTEM

The control system of the implemented model consist of four main block as shown in Fig3.First is the grid current processing block having PLL(phase locked loop) which filter current harmonics from controlled grid current controller(i_s) as a current controller. Third block is dc-link voltage controller which modifies the original reference voltage of the VSI by adding an extra term (u_v) to keep the dc voltage at its nominal value. Fourth block is pulse width modulator which generates the switching signals of the VSI (Sc) from the final reference voltage of the VSI (u_c)

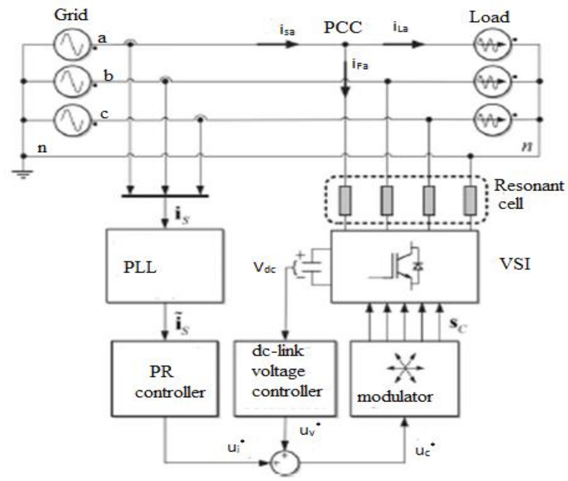

Fig 2: Complete model implemented in Matlab /Simulink

Currents signals at the input of current processing block can be sensed either upstream grid. The transfer function of the control system depends on both the current sensing point and the type of injected current controller. This current controller can work static reference frames using conventional resonant controller. The dc-link voltage controller generates a reference voltage in phase with the current at the fundamental grid frequency flowing through the VSI.

Interaction of both voltage and current generates an exchange of active power between VSI and the grid to keep the energy stored into the dc-link stored energy and so the dc-link voltage close to its nominal value.

4. CONTROLLER PERFORMANCE EVALUATION

The power quality of distribution systems has a strong effect on power regulation and consumption. The summation of all harmonics in a system is known as total harmonic distortion (THD).Non-linear loads represent current that is not perfectly sinusoidal. Since the current waveform deviates from a sine wave, voltage waveform distortions are created means harmonics are created. Harmonics have frequencies that are integer multiples of the waveform’s fundamental frequency means if 2nd, 3rd, 4th and 5th harmonic components will be at 120Hz, 180Hz, 240Hz and 300Hz respectively for 60 Hz fundamental frequency. The ideal sine wave has zero harmonic components so there is no distortion. Total harmonic distortion (THD) is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave,

$$THD = \frac{\sqrt{\left(V_2^2 + V_3^2 + V_4^2 + ...V_n^2\right)}}{V_1} *100\%$$

The above formula gives THD on a voltage signal. The final result is a percentage equating the harmonic components to the fundamental component of a signal. The greater the percentage, the high distortion that is present on

In Table 1 we can see that for the rated voltage at the PCC their should be specific limit for harmonic distortion. It is different for individual harmonic and different for total harmonic distortion. In this paper the grid voltage is taken in between 69 kV <V≤ 161 kV voltage limit. where the requirement of total harmonic distortion is should be less than or equal to 2.5 % and individual harmonic should be less than or equal to 1.5%.

Where,

a is Even harmonics are limited to 25% of the odd harmonic limits above.

TABLE I
VOLTAGE DISTORTION LIMITS

Bus voltage V at PCC	Individual Harmonic(%)	Total harmonic Distortion THD(%)
V ≤ 1.0KV	5.0	8.0
1KV < V ≤ 69KV	3.0	5.0
69KV < V ≤ 161KV	1.5	2.5
161KV < V	1.0	1.5[2]

TABLE II
CURRENT DISTORTION LIMITS FOR SYSTEMS RATED ABOVE 69KV THROUGH 161 KV

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order(odd harmonics)[a,b]						
I_{sc}/I_L	3 ≤ h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	35 ≤ h < 50	TDD
<20[c]	2.0	1.0	0.75	0.3	0.15	2.5
20<50	3.5	1.75	1.25	0.5	0.25	4.0
50<100	5.0	2.25	2.0	0.75	0.35	6.0
100<1000	6.0	2.75	2.5	1.0	0.5	7.5
>1000	7.5	3.5	3.0	1.25	0.7	10.0

b is Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

c is All power generation equipment is limited to these values of current distortion, regardless of actual Isc/IL.

where

Isc = maximum short-circuit current at PCC

I_L= maximum demand load current

Frequencies that are not integer multiple of fundamental frequency.User should limit t the components to required levels to avoid unwanted effect of harmonic distortion. Table.2 describes the current distortion limits for systems rated for the limit that is 69 kV to 161 kV. And the grid voltage taken in this project is 138 kV.

The Bode plot of Performance of PR controller used in the system for Kp =1,Ki=2,ω=2π60 is shown in Fig 3

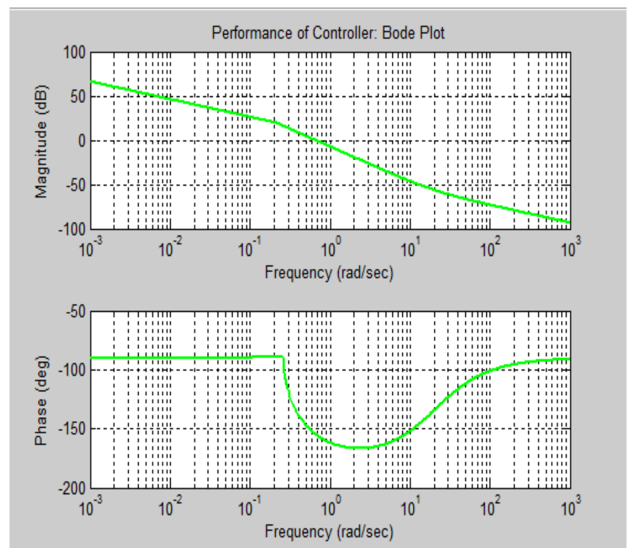

Fig 3 : Bode plot of Performance of controller

5. SIMULATION RESULT

In the model by using three phase fault and giving switching time to the circuit breaker there is generation of harmonics occurred. Therefore it produces current distortion in the power system which effect on the active and reactive power as shown in the Fig 4

The switching time of the circuit breaker is from 0.01 to 0.08 sec and we can see this in the Fig 4 that in between this given timing there is distortion of the waveform and after that it get its normal position because of using PR controller.

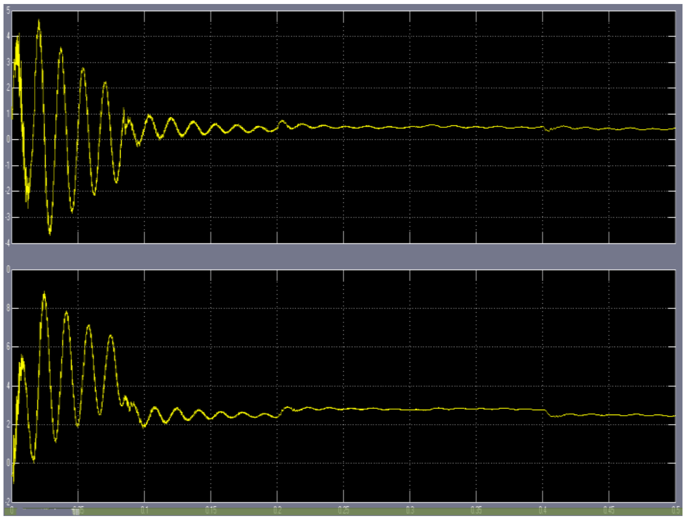

Fig 4: Active power and reactive power of the system

Case 1: *Performance of the system without controller*

In this case of the system without controller is described ,in which system having grid voltage 138 kV, fundamental frequency is 60hz and line length 100 m connected to the load. when fault is occurred in the system due to short circuit or switching of the circuit breaker. Due to which harmonics are created in the power system as shown in the fig 5 these harmonics have a total harmonic distortion 9.13% which is above the limit as per given IEEE standard in table 1 and 2 which are reduced by using PR controller in the power system.

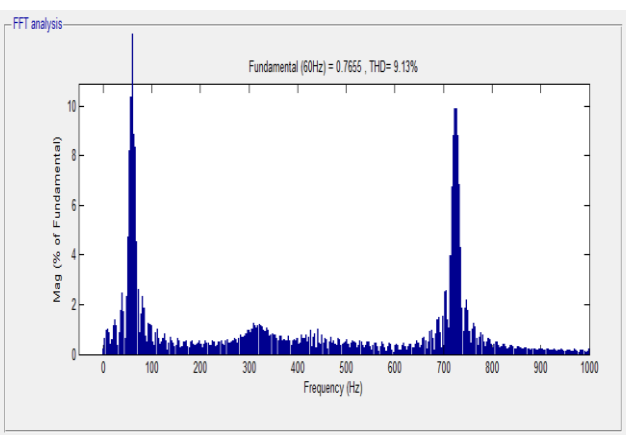

Figure5: FFT analysis without PR controller

Case2: Performance of the power system with controller

In this case we use proportional resonant(PR) controller for mitigation of harmonics which are produced due to short circuit condition or switching of the circuit breaker. In this paper for controlling power quality we have to use pulse width modulator(PWM) ,Phase locked loop(PLL) ,Voltage source Inverter (VSI) with the PR controller. Uses of all these results mitigation of harmonics shown in fig 6 where Total harmonic distortion is reduces 2.22% which is within specified limit as per Table 1 where the THD must be below 2.5% for the power system having the voltage in between 69 kV to 161 kV. In this project the grid voltage is 138 kV.

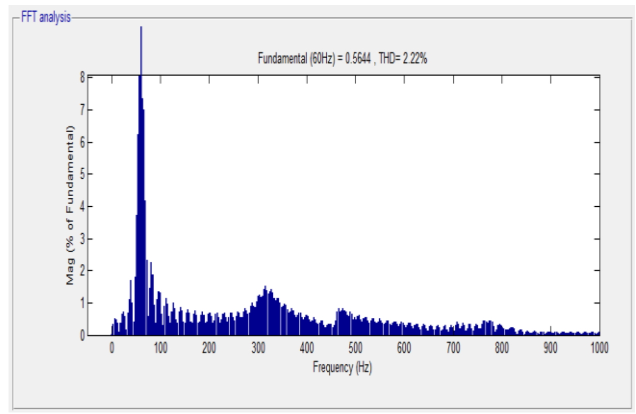

Figure6: FFT analysis by using PR controller

6. CONCLUSION

The power quality of distribution system has a major effect on power consumption and regulation. The addition of all harmonics in the power system is known as total harmonic distortion (THD).Generally non linear load causes to generate harmonics in the power system in this paper we take short circuit condition and give switching time to circuit breaker for generation of harmonics. All these produce current that is distorted from pure sinusoidal waveform as the current waveform deviates from the sine wave, voltage waveform distortion are created due to harmonics. Harmonics are the frequencies that are integer multiples of the waveform fundamental frequencies means 2^{nd} , 3^{rd} ,4^{th} and their harmonic component will be 120 hz,180 hz,240hz respectively for fundamental frequency 60 hz. For removing these harmonics we use PR controller which is used in current control for grid control application where the requirement are to synchronise the current with the constant grid frequency and compensate for the low harmonics by which we get proper operation of equipment and a longer equipment life. MATLAB/SIMULINK has been employed for presenting the simulation results and compare it with the system without PR controller because it is well established and recognized simulation software for the power system.

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