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Compensation Strategies of Railway Power Conditioner for Railway Traction Power Supply System

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Abstract:- By rapid development of high-speed locomotive load have some characteristics such as power factor, low harmonic and high negative sequence component became major problem They are many methods used to solve the above characteristics by connecting unbalanced load to high voltage terminals and FACTS (Flexible AC Transmission System) devices .But they can't adjust dynamically and its cost increases. The Railway Power Conditioner (RPC) is efficient in negative sequence Compensation under unbalanced load conditions and increasing the power factor. My works shows new railway negative unbalanced load system based on multiple RPC compensation with using Proportional Integral Derivative (PID) to reduce the high compensator capacity This work will be simulated in MATLAB Simulink and result are compared with the values given in reference paper (with PI controller) in terms of Complex Power, High Negative sequence component Including Harmonics and Power Factor.

Keywords:- Compensation, Negative Sequence Component, Harmonics.

I. INTRODUCTION

As developing of high-speed railways in China and Japan, power quality has become a major problem for power supply to locomotive loads [1]. For low speed locomotive load there is no problem of power factor they runs at low speed, high-speed locomotive load has some problems, Such as big instantaneous power supply, inducing the power factor, low harmonic components and high negative sequence component. To reduce this problem a large amount of negative current is injected into traction lines [2], which causes serious problem impact on power system, the dc series motor causes vibration and additional loss, they may causes the effect on the transformers [3].These adverse impacts threaten the safety of high-speed railway traction supply system and power system. Therefore, it's necessary to take measures to suppress negative current. The above chararactrics causes major problem for railway power supply to the locomotive loads to reduce all these problem, we are improving the power factor [3],[4],[5],[9].in order to solve the issue of power quality. The negative current is injected into the railways traction lines are as follows below:

(1) Connect unbalanced load to different supply terminals [3].
(2)Adopt phase sequence rotation to make unbalanced load distributed to each sequence reasonably [5].
(3) Connect unbalanced load to higher voltage level supply terminals.
(4)Use balanced transformers such as Scott transformer and impedance balance transformer [4].

The above all these methods are to matinee the power supply effects on railway traction line to reducing unbalance conduction, but they are lack of flexibility and can't adjust dynamically. As technology increases they are implemented many changes to improve the power factor such that.

A facts devices is used in present years, such as Static VAR Compensator (SVC), Active Power Filter (APF) and Static Compensator (STATCOM) have become focus on power quality compensation of electrified railway [5][6][7].For all the facts devices need high-voltage transformers which increase cost. Among all the devices the APF is effective in suppressing harmonic currents in railway traction line to inject the negative sequence compensation [8]. To decrease the cost by replacing the FACTS devices by three station RPC compensator to improve the power factor.

II. THREE STATION RPC AND ANALYSIS OF COMPENSATION.

In the Reference Paper [14] the author is explained how to make the 5-6 locomotive loads from unbalance conduction to balanced conduction, with the help of PI controller. To improve power factor of electrical locomotive must be closer to 1, In this paper.To improve the power factor a new device of with three stations RPC with Proportional Integral Derivative (PID) controller technique is used to operate the breaker at unbalanced conduction to make balanced conduction at 0.2sec,0.3sec,0.5sec.Reference [10] and [11] put forward a proposal of Railway Power Conditioner (RPC), RPC can make comprehensive compensation of negative sequence Components, harmonics and reactive power.

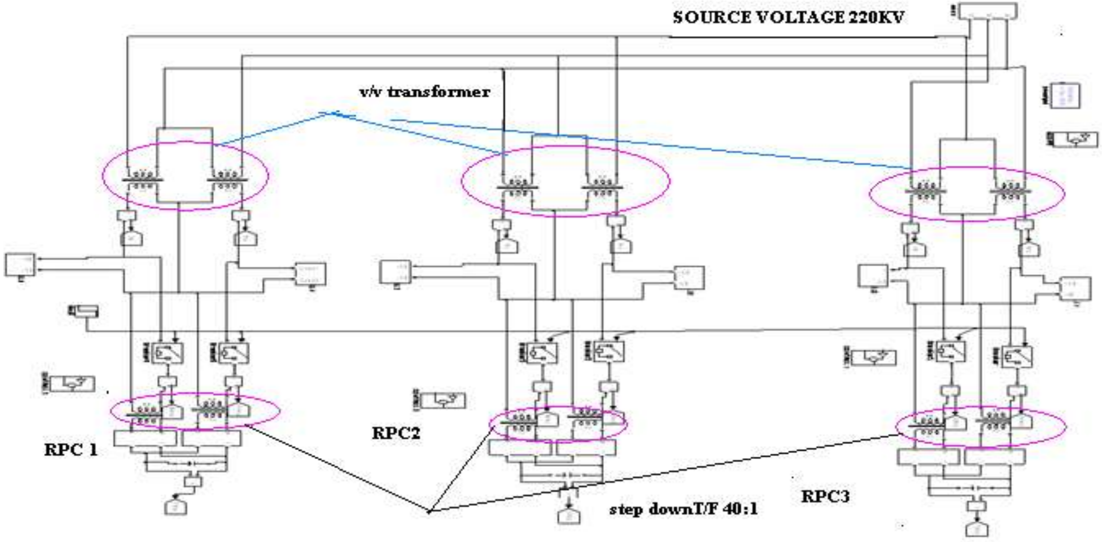


Fig1: A Simulation Diagram of Three Station RPC Compensation

In this above simulation diagram fig.1 the supplied power from generation station 220kV voltage is stepped down into two single-phase power supply voltage in to range of 27.5kV by V/V transformer (**Marked in Above Fig 1 With Pink Color)** connected one line to conductor another line to tracks of railway traction. The three RPC1.RPC2, RPC3 is made of IGBT with diode connected back-to-back voltage source converters (VSC) at both sides of dc capacitor to provide dc-link voltage stable. From two converters one can transfer active power from one side arm and another one supply reactive power from second arm to reduce the harmonic currents. From one RPC1 right feeder section in Fig.1 is denoted as *a*-phase power arm is connected from Phase a conductor, similarly the left side is *b*-phase power arm is connected from Phase b connected Assume that the fundamental current vector of *a*-phase power arm is I_{aL} and the fundamental current vector of b-phase power arm is I_{bL} are shown as follows:

$$I_{aL}=I_{aL*}e^{-j3} \quad (1) \qquad \dot{I}_A = I\frac{\dot{I}_{AL}}{K} = \frac{I_{AL}}{K}e^{-j30} \quad (3)$$

$$I_{bL}=I_{bL*}e^{-j30} \quad (2) \qquad \dot{I}_B = I\frac{\dot{I}_{bL}}{K} = \frac{I_{bL}}{K}e^{-j30} \quad (4)$$

When unbalanced conduction RPC compensation, *a*-phase power arm has load current I_{aL} and the *b*-phase power arm has load current I_{bL} so that the phase current $I_{AL} \geq I_{BL}$ To compensate the locomotive loads from unbalanced conduction to balanced conduction. We arranged the breaker to compensate the effected line with RPC.

To shift $\frac{1}{2}(I_{aL} - I_{bL})$ from both phases-b. When the lines are compensated I_{aL}, I_{bL} *to* I_{AL}, I_{BL} and they have equal amplitude $\frac{1}{2}(I_{aL} + I_{bL})$ and an angle difference of $\Pi/3$ .The unbalance level is 50% now. To make the locomotive loads from unbalanced conduction to balanced conduction a negative current is injected from dc capacitor from the both sides of transformer, A-phase current is I_{acq},and simulary b-phase current is I_{bcq}

$$I_{acq} = \tfrac{1}{2}(I_{aL} + I_{bL})\tan 30 \qquad (6)$$

$$I_{bcq} = \tfrac{1}{2}(I_{aL} + I_{bL})\tan 30. \qquad (7)$$

In the below fig2 is the control block diagram of the three station RPC, here output 1 &2 are connected to add when the traction is at unbalanced conduction the error value is of two o/p is added to the add that error value is make product to the either sin terms or cosine terms it depend up on the error with the help of the condoler

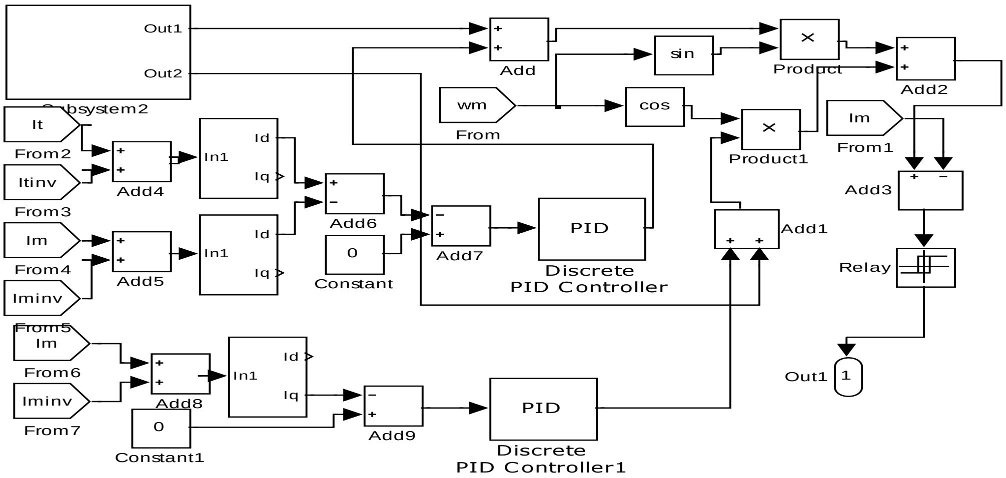
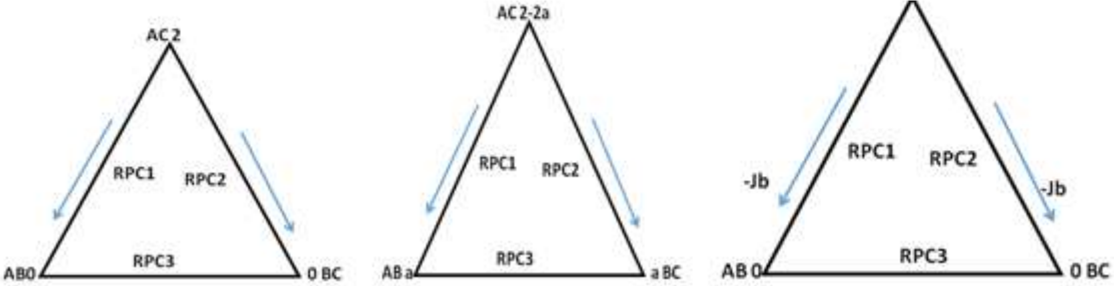


Fig2: Simulation diagram of three station control by PID controller

Since phase sequence rotation is widely adopted in traction power supply system, 3 stations collaboration compensation is mainly discussed in this paper. The capacity in phase AB, BC and CD is x,y,z , which has a relationship of *x>y>z*. The network of AB, BC and CD can be divided into two parts, one network is used to balanced the railway power supply Z, the other network is used to unbalanced the railway power supply at conduction x-z*, y-z, 0*. Here X=x-y, Y=y-z, Z=0, the original network is simplified as 0, *YX*. Set *X*/2 as the reference value, the P.U. value of the simplified network is 2, Y' 0. Y' Is varying from 0 to 2. The extreme case is Y' =0. The optimize compensation strategy is shown below. The model of 3 station RPC structure is shown in fig 1.To make balanced conduction active and reactive power injecting under unbalanced conduction. Are shown in triangle diagram of phase-AC, phase-BC, and phase-AB. In below diagram . The arrow mark diagram shows the active power (real part) and reactive power (imaginary part) to balance the railway power supply. The network is based on the Steinmetz theory.



(a)Active power deliver (b)Three phase power after active power (c) Reactive power compensation based on Steinmetz theory

III. STEINMETZ THEORY

According to the Steinmetz theory, In Reference Paper [14] a and b values are take as 1/3 and we make the breaker to operate at 0.5sec. In this paper the breaker is operated at 0.2sec, 0.3sec, 0.5sec.The fully compensation should satisfy the relationship of $b+c \geq \frac{2-3a}{\sqrt{3}}$. The capacity of three RPC is $\sqrt{a^2+b^2}$, $\sqrt{a^2+b^2}$, c separately. The installed capacity will be the maximum of the three RPC capacities above. So we can obtain the minimum installed capacity when. $\sqrt{a^2+b^2}$ =c.The results can be conducted that a= $\frac{1}{4}$, b= $\frac{1}{\sqrt[3]{4}}$ and the minimum capacity is $S_{\min} = \sqrt{a^2+b^2}$ =c, $S_{\min} = \sqrt{1/4 + 1/\sqrt[3]{4}}$ =c. This is a fully compensation but the station where RPC2 installed is capacitive. To avoid this condition, RPC1 supply inductive reactive power with the value of *b*, and RPC2 supply capacitive reactive power with the value of *b*, too. So the capacitive condition is avoided and the system keeps balance at the same time.

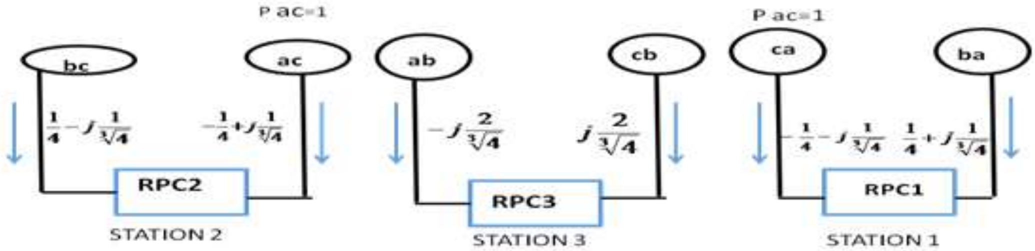


Fig3. Working condition of three stations injecting active power and reactive power.

The two strategies. $S_{\min} = \sqrt{\frac{1}{4} + \frac{1}{\sqrt[3]{4}}}$ .Which is 2/3 of the capacity of single RPC compensation. Set three station collaboration compensation for example. Fig 1. Shows the schematic diagram of three station collaboration compensation. Three typical conditions are taken in to consideration.

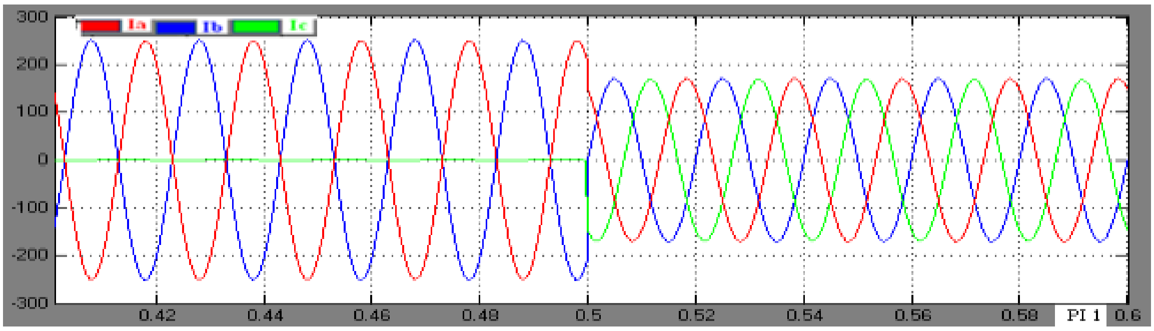
The simulation parameters are the same as single station compensation. Simulation results are shown in Figure 8(a) shows the waveform when they are at unbalanced and balanced conduction or before and after compensation when the unbalanced conduction occur

$$Y = 0 : 2) 0 \le Y \le \frac{2}{3} : 3) \frac{2}{3} \le Y \le 1$$

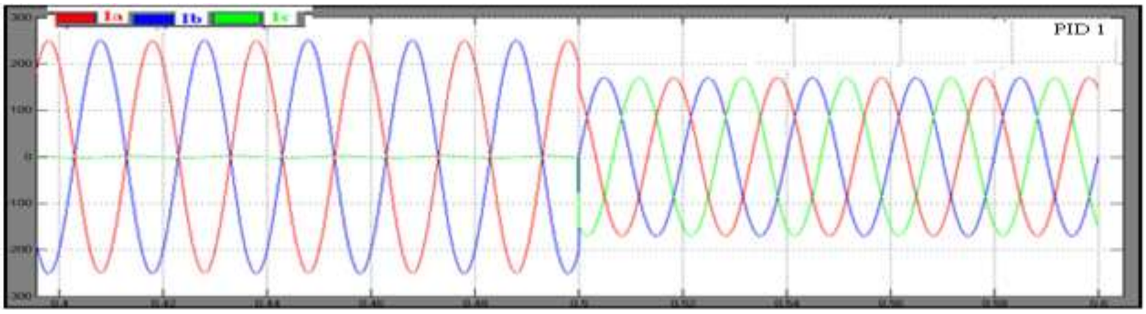
When the maximum locomotive load appears at the Phase-AC at the condition of *Y*=0. The situation before compensation is almost the same as single station compensation, except for that the load is twice as much as single station locomotive load. With the use of compensator, the unbalance level was changed from3.53 to 3.29 .Fig.8 (b) is the waveform when 0<Y<2\3 , appears at Phase AB. Compensator was put into operation at 0.5*s*.

The unbalance level was reduced from 0.34 to 0.47. The waveform when 2\3<Y<1is shown in Fig 8 (c). The unbalance level was reduced from 4.19 to 3.81. It can be seen from the simulation that there is a serious unbalanced condition before the compensation. The collaboration compensation network is effective in reducing the negative current (the unbalance level is reduced below 0.4. The error may come from the loss of power electronic components and isolation transformers. The unbalance level before and after the compensation is listed in

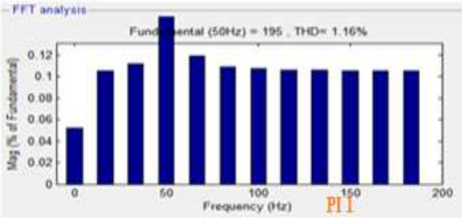
IV. COMPARING THE SIMULATION RESULTS OF PI AND PID CONTROLLER



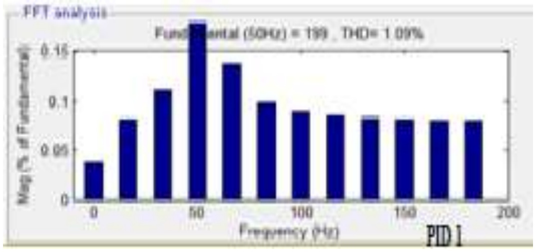
(i)Reference Paper Shown In PI Controller(Y=0)



(ii)Results with PID Controller(Y=0)



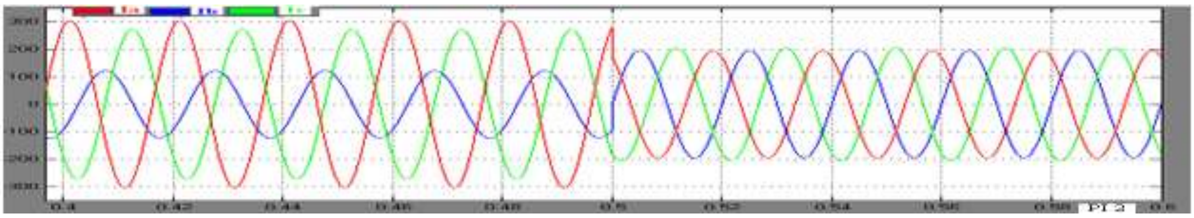
(iii) THD Value For Reference Paper



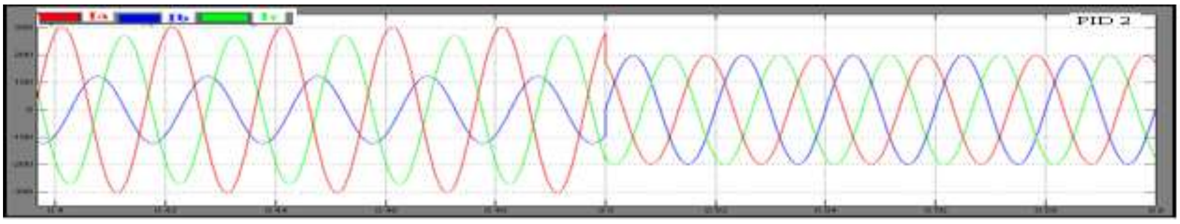
(iv) THD Value For PID Controller

8(a) Current of tractive transformer high voltage side(Y=0)

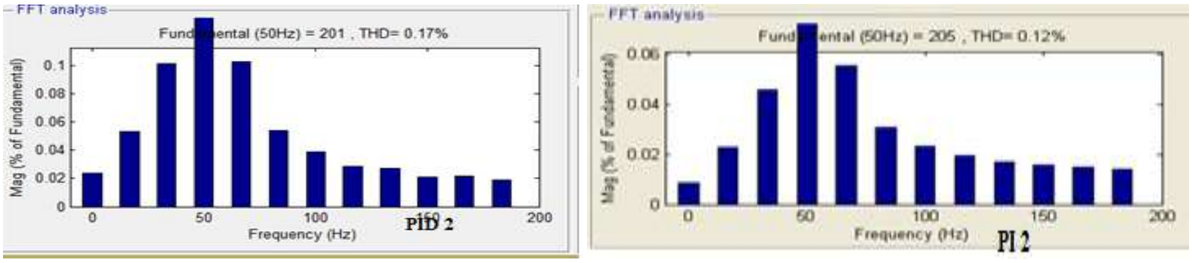
From above simulation waveform (i) are the reference paper [14] results, these results are at ,when the breaker is operated at 0.5 sec and THD values are absorbed in waveform (iii).All these THD values(iv) and simulation wave (ii)form are compared with PID controller to make the traction line from unbalanced conduction to balanced conduction. So, by PID controller the breaker will operate faster at less time at Y=0 conduction.



(i)Reference Paper Shown In PI Controller (0<Y<2\3)



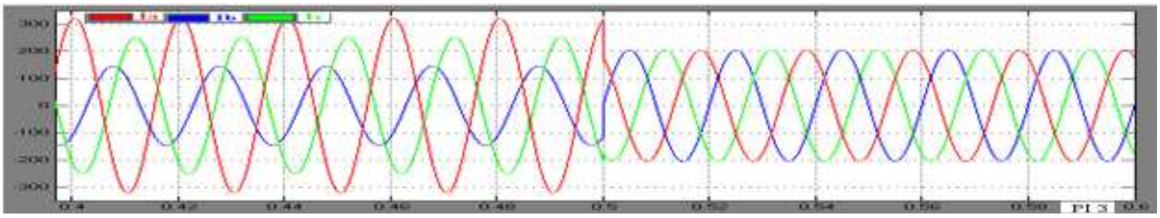
(ii)Results with PID Controller (0<Y<2\3)



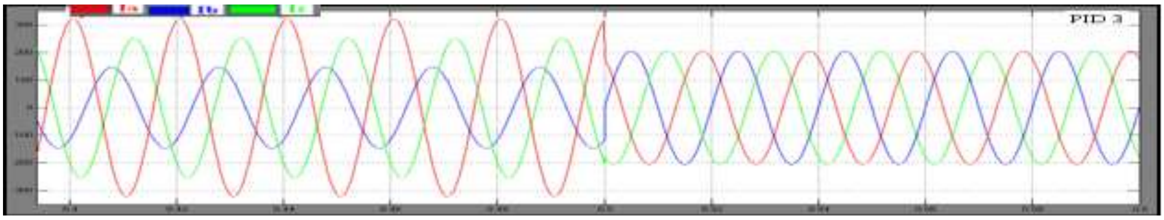
(iii) THD Value For Reference paper **(iv) THD Value For PID Controller**

8(b) Current of tractive transformer high voltage side (0<Y<2\3)

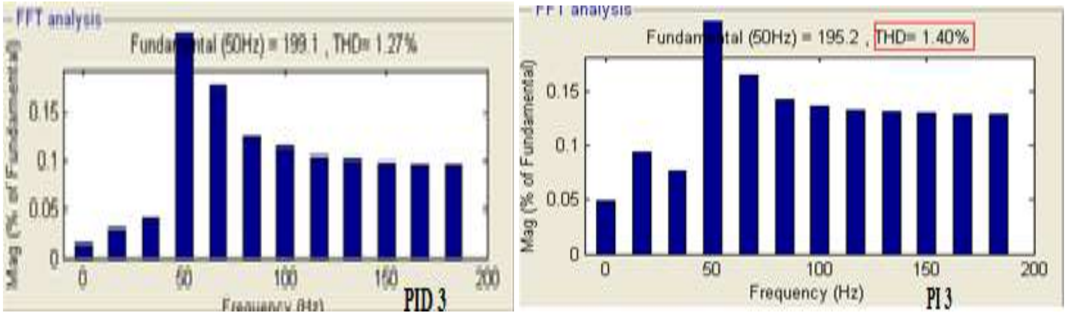
From above simulation waveform (i) are the reference paper [14] results, these results are at ,when the breaker is operated at 0.5 sec and THD values are absorbed in waveform (iii).All these THD values(iv) and simulation wave (ii)form are compared with PID controller to make the traction line from unbalanced conduction to balanced conduction. So, by PID controller the breaker will operate faster at less time at 0<Y<2/3 conduction.



(iii)**Reference Paper Shown In PI Controller (0<Y=1)**



(iv) **Results with PID Controller (0<Y<2\3)**



(iii) THD Value For Reference paper **(iv) THD Value For PID Controller**

8(c) Current of tractive transformer high voltage side(2\3<Y<1)

From above simulation waveform (i) are the reference paper [14] results, these results are at ,when the breaker is operated at 0.5 sec and THD values are absorbed in waveform (iii).All these THD values(iv) and simulation wave (ii)form are compared with PID controller to make the traction line from unbalanced conduction to balanced conduction. So, by PID controller the breaker will operate faster at less time at 2/3<Y=1 conduction

In the below table the three cycles of the THD values are compared with the reference paper with PI controller. In cycles 1 it has three signals, in signal 1 the PID controller is compensated the THD value from 3.53% to 3.29% similar the signal 2 and signal 3 are compensated the THD value from 0.34% to 0.47% and 4.19% to 3.81% to make the unbalanced conduction to balanced conduction when the breaker is operated at 0.5sec.

In cycles 2 it has three signals, in signal 1 the PID controller is compensated the THD value from 1.74%to 1.65% similar the signal 2 and signal 3 are compensated the THD value from 0.20% to 0.24% and 2.10% to 1.91% to make the unbalanced conduction to balanced conduction when the breaker is operated at 0.5sec.

1SNO	CONTROLLER		TOTAL HORMONIC DISTORSTION(0.5Sec)		
			PI	PID	Total
1	CYCLE 1	signal 1	3.53%	3.29%	-0.24%
2		signal 2	0.34%	0.47%	0.13%
3		signal 3	4.19%	3.81%	-0.38%
1	CYCLE 2	signal 1	1.74%	1.65%	-0.09%
2		signal 2	0.20%	0.24%	0.04%
3		signal 3	2.10%	1.91%	-0.19%
1	CYCLE 3	signal 1	1.16%	1.09%	-0.07%
2		signal 2	0.12%	0.17%	0.05%

3		signal 3	1.40%	1.27%	-0.13%

TABLE1:-Compression of THD Values With PI and PID Controller

In cycles 3 it has three signals, in signal 1 the PID controller is compensated the THD value from 1.16% to 1.09% similar the signal 2 and signal 3 are compensated the THD value from 0.12% to 0.17% and 1.40% to 1.27% to make the unbalanced conduction to balanced conduction when the breaker is operated at 0.5sec.

V. CONCLUSION

This work simulated in Matlab Simulink and results are compared with the reference Paper [PI Controller] and PID Controller and the Total Harmonic Distraction (THD) with three different cycles values are observed in the given table to make unbalanced conduction to balanced conduction ,when the breaker is operated is at 0.5sec to reduce the Complex Power, High Negative Sequence Component including Harmonics and Power Factor with PID controller .

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[14]. A Novel Collaboration Compensation Strategy of Railway Power Conditioner for a High-Speed Railway Traction Power Supply System Chenmeng Zhang(Student), Baichao Chen, Chao Cai, Mengkui Yue, Cuihua Tian, Bo Chen, Jiaxin Yuan*(*Corresponding Author) Wuhan UniversityWuhan, Hubei, China Jiabin JiaUniversity of LeedsLeeds, UK