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# Implementation of Variable Hysteresis Band Current Control Technique for Three Phase PWM Rectifier Under Unbalanced Input Impedance Condition.

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**Abstract:-** This paper presents a closed loop control strategy to eliminated harmonics present at input and output side of rectifier when rectifier operate under unbalance input impedance condition. The unbalance present at input side of rectifier cause even harmonic at DC output side and odd harmonic in the input current as well as it affect the cost of DC side capacitor and AC side filter. To improve the performance of PWM rectifier, variable hysteresis current control technique has been implemented. Hysteresis current controller of variable bandwidth is used to track line current of all the three phases independently.

**Keywords:-** Harmonics, Pulse width modulation (PWM) rectifier, Unbalanced input condition, Hysteresis controller..

## I. INTRODUCTION

Recent years the PWM rectifier has been widely used because it offers the possibility of low distortion line current with nearly unity power factor at any load condition [1]. It has advantages like instantaneous reversal of power flow, controllability of DC link voltage. PWM rectifier has wide application such as in uninterruptible power supply (UPS) system, for front end converter, renewable energy system, medium voltage (MV) high power application and also in regenerative low voltage (LV). However for given application stated above PWM rectifier is designed under consideration of balanced input condition. Unfortunately the benefits stated above are not fully realized under unbalanced input condition [2]. Unbalanced input condition can occur for a variety of reason such as non-uniformly distributed single phase load, faults, weak input supply or unsymmetrical nature transformer windings. These unbalance condition cause imbalance in the three phase supply both in magnitude as well as in phase angle.

The unbalance input voltage or impedance will be source of abnormal second harmonic at DC bus which reflect back to input causing flow of third order harmonics current. Thus the third order harmonic current causes a fourth order harmonic voltage on the DC bus and so on. This results in appearance of even harmonic at the DC output and odd harmonic in the input current. This cause adverse effect on system and make system unstable [3].Unbalance input condition are responsible for producing many problems in the operation of static converters like signal interference, relay malfunctioning, over voltage and excessive current as a result of resonance due to harmonic voltage or current in the network. The excessive losses in terms of heat in rotating machine and error in induction type KWH meter [4].

Since European EN50160 standards allows 6% low order supply voltage harmonic and supply voltage sag/swells within $\pm$10%. Normal performance of PWM rectifier should be ensured under such varying and unbalanced supply voltage condition. Two approach are feasible to eliminate the harmonics appearing at the output DC link voltage and line side current. One approach is to use bulk filter to remove the ripple in the output voltage and input current. However it would slow down the dynamic response of the PWM boost rectifier. The other alternative is to use active control scheme to minimize the harmonics so that small size input/output filters can be used. This will also improve dynamic response of the PWM rectifier.

This paper presents variable hysteresis current control technique to reduce harmonic present at input and output side of rectifier under unbalance input impedances. Whether ever unbalance input impedances present high quality of input currents and output DC voltage are obtained. Here variable bandwidth of hysteresis current controller is used to track line current of all the three phases independently.

## II. LITERATURE REVIEW

### A. Feed-forward control method

A.V.Stankovic et al. [5] present a new closed loop control strategy to improve the performance of PWM boost type rectifier by eliminating completely input output harmonic under input unbalance voltage condition. The proposed method go through two disadvantage like power factor can not be adjusted and it can not operate under extreme unbalance condition. With respect to above approach A.V.Stankovic et al [6] proposed a method for PWM boost type rectifier under unbalance input voltage as well as unbalance input impedance. The proposed technique clears problem of adjustable power factor under input unbalanced operating condition. A.V.Stankovic et al [7] has proposed technique for complete harmonic elimination of PWM boost type rectifier at unity power factor under extreme unbalanced condition. The main advantage of that proposed method, PWM boost type rectifier can operate from the single phase supply in case where three phase source is not available.

**B. Repetitive control scheme**

Shinji Hara et al. [9] implemented a repetitive controller for three phase PWM rectifier in continuous time domain. To compensate all high frequency components in periodic reference input or disturbances by continuous time repetitive controller an unrealistic requirement for a proper controlled plant must be improved to assure stability. This requirement of controller overcome by Masayoshi et al.[10] by designing repetitive controller in discrete time domain. Discrete time domain limits the highest frequency components. It has an application in disk-file actuator system. X. H. WU et al. [11] design a repetitive controller in frequency domain for three phase PWM rectifier for DC link voltage and supply side current harmonics under unbalanced operating conditions. The main advantage of designing RC in frequency domain is the simplicity in control algorithm and real time implementation. The controller design would be easier in frequency domain than in time domain. Frequency domain repetitive controller enhances the robustness of the control system.

**C. Vienna Rectifier**

Traditionally three phase diode rectifier and thyristor rectifier are widely used in common AC-DC power conversion and rectifier-inverter based AC motor drives however such topology draw pulsed current from AC mains, causing low input power factor (PF)and large current harmonics pollution into utilities, resulting in increased distortion of supply voltage and losses contributing to inefficient use of electrical energy. In recent year various controlled technique has been proposed in order to reduce the voltage stress on power switches. The rectifier with variable switching frequency controller results in heavy interaction between phases when midpoint of DC link capacitor is not connected to the ground or source neutral of controlled rectifier. This results in acoustic noise, high switching losses and difficulty in designing input filter. C. Qiao. et al. [12] proposed constant frequency integration controller for three phase star connected switch three level rectifier (VIENNA) with continue conduction mode at unity power factor correction. The proposed controller can operate by sensing either inductor current or switching current. The operation of VIENNA rectifier at constant switching frequency not only reduce the harmonics at DC side of rectifier but also the voltage stress on power switch devices over two level converter. However when the neutral point potential operation imbalance, the capacitor voltage exceed half of DC link voltage which increase the voltage stress of power devices. LiGao He et al. [13] proposed a neutral point potential balancing controller for three level three switch VIENNA rectifier base on balance factor correction by measurement of input phase current. The proposed method balance neutral point potential with small variation by generating duty cycle of PWM signal with the help of real time calculation. June-Seok Lee et al. [14] introduced carrier based discrete PWM for VIENNA rectifier. The proposed method has high efficiency compare to carrier based continuous PWM method.

**D. Hysteresis controller**

Kolar et al. [15] proposed a three phase, three switch, three level unidirectional rectifier controlled with conventional fixed band hysteresis current control. For power factor correction it uses DC/DC boost converter series with rectifier. The major drawback of constant hysteresis band is supply current harmonics distributed through a wide frequency spectrum from hundreds of Hertz to several kilo Hertz. This variable frequency causes increased switching losses, acoustic noise and complicated input filter design. Ali Maswood et al.[16] proposed a novel variable hysteresis band current control technique for three phase three level bidirectional switch front end rectifier of an adjustable speed drive (ASD). With the help of variable hysteresis band current control technique supply current harmonics concentrate around a constant switching frequency which helps in converter design and operation. Proposed converter exhibits a good adaptability to sudden load variation. Disadvantage of proposed technique is large input inductance required to achieve unity power factor. This problem overcomes by fangrui et al. [17]. With respect to above approach [17] proposed a method for three phase three level unity PF rectifier. Main advantage of that method is replacing low frequency R-L-C tuned filter by RC high pass filter with much lower KVA ratings. Absence of any input inductance or filter results in a lightweight structure for hardware. In all above proposed work three phase diode rectifier are used. Suhara E M et al. [18] analysis current control technique for three phase PWM rectifier. The use of PWM converter for rectification purpose corrected power factor. Along with that advantage grid side power is not polluted as it able to control the input current magnitude as well as phase angles to meet with power quality requirements. [18] Present a comparative study of different types of hysteresis controller namely constant hysteresis band, sinusoidal hysteresis band, adaptive hysteresis band and simplified adaptive hysteresis band for input current control.

## III. THEORETICAL APPROACH

The PWM rectifier is shown in Fig.(1). It is assumed that input voltage is balanced but input impedance is unbalanced. Harmonic elimination can be achieved by generating unbalanced command for three input currents under unbalanced input impedances [7].

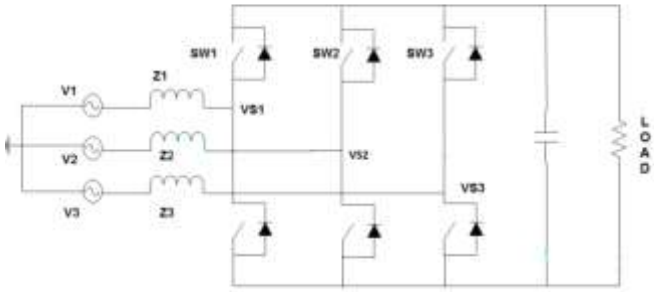


**Fig.1**: PWM rectifier

Where,

| | |
|---|---|
| $V_1,V_2,V_3$ | : Input voltages for three phases |
| $I_1,I_2,I_3$ | : Input currents for three phases |
| $Z_1,Z_2,Z_3$ | : Input impedances for three phases |
| $V_{S1},V_{S2},V_{S3}$ | : Synthesized voltages |
| $SW_1,SW_2,SW_3$ | : Switching function for three phases |
| $V_1^*,V_2^*,V_3^*$ | : Conjugate of input voltages for three phases |
| $S,S^*$ | : Apparent power and conjugate of apparent power |
| $V_{dc}$ | : DC output voltage |

Three phase input voltages are,

$$V_1 = Z_1 I_1 + V_{S1} \quad (1)$$

$$V_2 = Z_2 I_2 + V_{S2} \quad (2)$$

$$V_3 = Z_3 I_3 + V_{S3} \quad (3)$$

Synthesized voltage can be expressed as,

$$V_{S1} = SW_1 \times \frac{V_{dc}}{2\sqrt{2}} \quad (4)$$

$$V_{S2} = SW_2 \times \frac{V_{dc}}{2\sqrt{2}} \quad (5)$$

$$V_{S3} = SW_3 \times \frac{V_{dc}}{2\sqrt{2}} \quad (6)$$

By substituting (4)-(6) into (1)-(3). The (7)-(9) equations are obtained,

$$V_1 = Z_1 I_1 + SW_1 \times \frac{V_{dc}}{2\sqrt{2}} \quad (7)$$

$$V_2 = Z_2 I_2 + SW_2 \times \frac{V_{dc}}{2\sqrt{2}} \quad (8)$$

$$V_3 = Z_3 I_3 + SW_3 \times \frac{V_{dc}}{2\sqrt{2}} \quad (9)$$

$$I_1 + I_2 + I_3 = 0 \quad (10)$$

Complex of apparent power is,

$$S^* = V_1^* I_1 + V_2^* I_2 + V_3^* I_3 \quad (11)$$

By multiplying equations (7), (8), (9) by $I_1$,$I_2$, $I_3$ respectively and adding them up following equation is obtained,

$$V_1 I_1 + V_2 I_2 + V_3 I_3 = Z_1 I_1^2 + Z_2 I_2^2 + Z_3 I_3^2 + \frac{V_{dc}}{2\sqrt{2}}(SW_1 I_1 + SW_2 I_2 + SW_3 I_3) \quad (12)$$

$$SW_1 I_1 + SW_2 I_2 + SW_3 I_3 = 0 \quad (13)$$

from equation (12) and (13),

$$V_1 I_1 + V_2 I_2 + V_3 I_3 = Z_1 I_1^2 + Z_2 I_2^2 + Z_3 I_3^2 \quad (14)$$

Equation (13) represented the condition for second order harmonics elimination. Equation (10), (11) and (13) represent a set of three equations with three unknowns. After solving these equations for three phase line current $I_1$, $I_2$ and $I_3$ with all parameters known such as input complex power $S$, input voltages $V_1$, $V_2$ and $V_3$, input impedances $Z_1$, $Z_2$ and $Z_3$ result in quadratic equation in terms of $I_3$. The correct value is select based on phase sequence of solution.

$$\left\{ \begin{array}{l} \left[ \frac{2Z_1(V_3^* - V_1^*)}{V_2^* - V_1^*} - \frac{(Z_1 + Z_2)(V_3^* - V_1^*)^2}{(V_2^* - V_1^*)^2} - (Z_1 + Z_3) \right] I_3^2 + \\ \left[ (V_3 - V_1) - \frac{(V_3^* - V_1^*)(V_2 - V_1) - 2Z_1 S^*}{(V_2^* - V_1^*)} + \frac{2S^*(Z_1 + Z_2)(V_3^* - V_1^*)}{(V_2^* - V_1^*)^2} \right] I_3 + \\ \frac{S^*(V_2 - V_1)}{(V_2^* - V_1^*)} - \frac{(Z_1 + Z_2) S^{*2}}{(V_2^* - V_1^*)^2} \end{array} \right\} = 0 \quad (15)$$

The phase current $I_2$ can be obtained using equation (15). There are,

$$I_2 = \frac{S^* - I_3(V_3^* - V_1^*)}{(V_2^* - V_1^*)} \quad (16)$$

Equation (10) is used to calculate $I_1$.These line currents from Equations (10), (15) and (16) are used as reference currents for harmonic elimination under unbalanced input impedances.

## IV. CONTROL METHOD

Schematic diagram for implementation of three phase PWM rectifier for unbalanced input impedance condition is shown in fig(2).The PWM rectifier is operated at near constant switching frequency method. The input-output harmonic elimination method is used to calculate the magnitude and phase angle of the reference currents. There are three input sinusoidal voltage sources representing a three phase input supply. Three input inductors connected with the three phases represent the input impedances. There are six IGBTs connected with anti-parallel diode representing the bidirectional switches of the PWM three phase rectifier. The rectifier output is given to two identical series-connected DC link capacitors. The voltage at midpoint of the two capacitors with respect to AC side neutral point is used to calculate neutral current. Here the current controller is a hysteresis controller with variable bandwidth and is used to track line current of all the three phases independently. Measured value of three phase currents ( $I_a, I_b, I_c$), calculated neutral current $I_O$ , and hysteresis bandwidth (*h*), are inputs to the controller as shown in Fig.2 The output of the controller gives gate signals to all six IGBTs of the converter module. Equation (17) presents instantaneous value of the bandwidth of hysteresis controller *h* required to keep the switching frequency constant at a pre-set value *fs* [8].

$$h = \frac{\left(\frac{V_{dc}}{2}\right)^2 - \left(|V| - L\frac{d|i^*|}{dt}\right)^2}{2 \times L \times f_s \times V_{dc}} \quad (17)$$

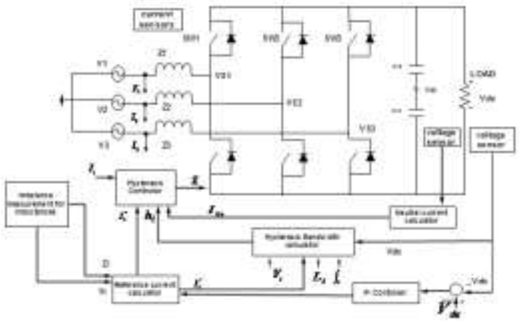

**Fig.2:** Schematic diagram for implementation of three phase PWM rectifier for unbalanced input impedance condition.

The hysteresis bandwidth *h* varies in time and is periodic in nature. The frequency of hysteresis bandwidth plot is twice as that of fundamental frequency and is cosine in nature as it is shifted by 90 degree from the fundamental component. The bandwidth *h* depends on the values of output dc voltage, source instantaneous value of voltage, source input inductance, reference current and frequency of operation set.

## V. SIMULATION RESULTS

The unbalance at source side of rectifier is done by unbalancing source impedances. There are four simulation results shown of supply AC current and DC output voltage for balance and unbalance condition. Parameter used in simulation is shown in table 1. Input current THD, input inductance and output voltage at different cases are shown in table 2.

**Table 1.**Parameter used in simulation

| Sr. No | Input L inductances | | | Fundamental frequency | Input supply voltage | | | Output resistive load |
|---|---|---|---|---|---|---|---|---|
| | L1 | L2 | L3 | | V1 | V2 | V3 | |
| 1. | 10mH | 10mH | 10mH | 50Hz | 60∟0 | 60∟-120 | 60∟120 | 150Ω |

Simulation results of case1 shows balance condition. At second case one phase is unbalance by placing one phase inductance value other than 10mH here 2mH is taken. Same applied for case 3 and case 4.

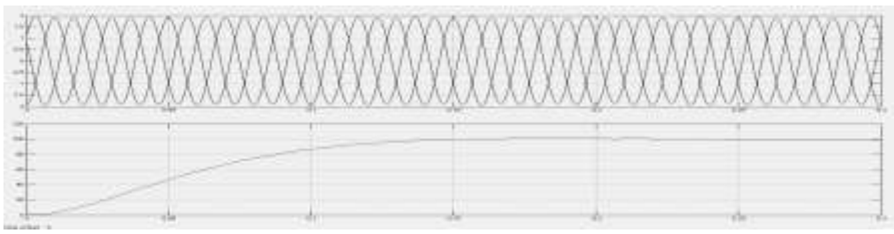

**Fig3:**case1output DC voltage and input AC current at balance condition

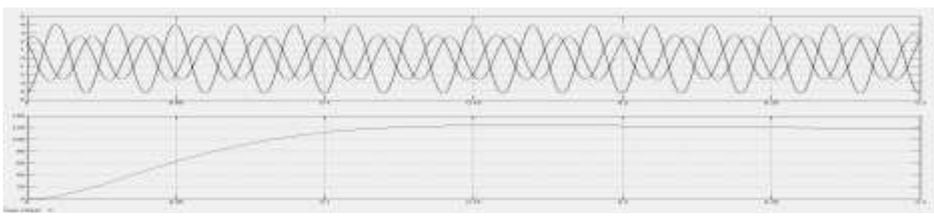

**Fig4:** case2 output DC voltage and input ac current at one phase unbalance condition. .

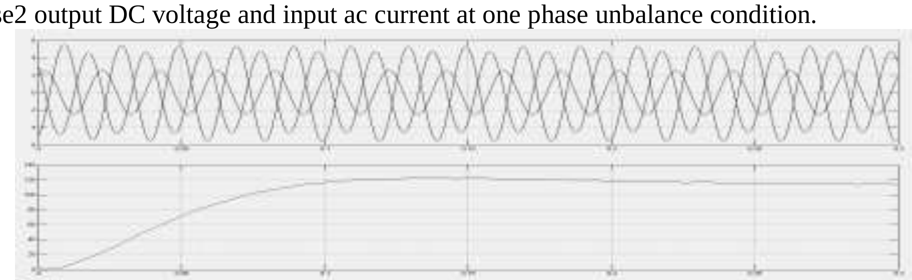

**Fig5:**case3 output DC voltage and input AC current at two phase unbalance condition.

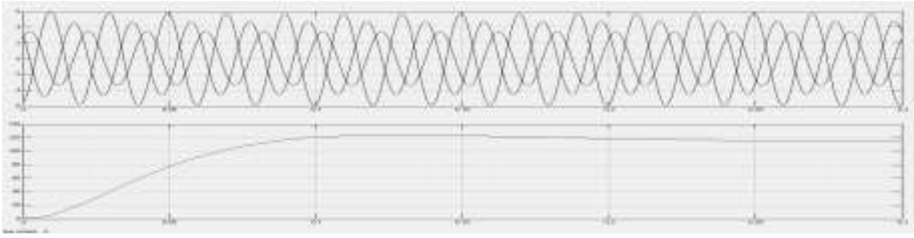

**Fig6:** case4 output DC voltage and input AC current at three phase unbalance condition.

**Table 2**: Simulation results

| CASE | INPUT INDUCTANCE | | | INPUT CURRENT THD | | | OUTPUT VOLTAGE(V) |
|---|---|---|---|---|---|---|---|
| | **L1** | **L2** | **L3** | **I1** | **I2** | **I3** | |
| 1 | 10mH | 10mH | 10mH | 0.12% | 0.4% | 0.31% | 115 |
| 2 | 2mH | 10mH | 10mH | 0.44% | 0.6% | 0.14% | 119 |
| 3 | 2mH | 5mH | 10mH | 1.01% | 1.02% | 0.32% | 120 |
| 4 | 2mH | 5mH | 7mH | 0.87% | 1.04% | 0.21% | 122 |

## VI. CONCLUSION

This paper presents the implementation of sinusoidal variable hysteresis band current controller for three phase PWM rectifier operating at constant switching frequency 9 kHz with unity power factor. The closed loop technique is used to adjust the DC link voltage and elimination of input harmonics by updating reference current through feedback loop. The calculation of bandwidth for grounded midpoint DC link capacitor is then extended to floating condition using neutral current addition in current controller. This method reduce the harmonic contain in source current to lowest value and voltage controller is used to produce the reference current proportional to input power needed to maintain DC link voltage constant. The simulation results shows that the controller not only exhibits excellent adaptability, input harmonic reduction for unbalance input condition but also providing high reliability and simple controller at unity power factor.

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