Performance Enhancement of a Three-Phase Buck Converter using FOPI control under Unbalanced and Variable Grid Frequency conditions

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ABSTRACT: This paper presents the implementation of the FOPI control scheme for a three-phase buck rectifier (3ph-BR). In this work, a simple, PLL-free, and frequency-independent flexible power control strategy is established to operate the 3ph-BR converter effectively. The proposed FOPI control scheme seamlessly operates the 3ph-BR converter under unbalanced voltages and wide grid frequency variations. 3ph-BRs are often used in applications like electric vehicles and more electric aircraft. Due to asymmetric transmission impedances, faults, or sudden step changes in the load, the output voltage and grid-side input currents can become distorted. These unbalanced grid voltages degrade the overall performance of the 3ph-BR converter. To address this problem, existing traditional methods rely on Phase-Locked Loops (PLL) to extract positive and negative sequence voltages. These traditional components must know the grid frequency in advance and require time to detect the phase and frequency. Delays in estimating frequency variations result in severe current distortion and output voltage fluctuations. These detrimental effects destabilize the system's performance. To overcome this problem and regulate the 3ph-BR converter's output voltage, a fractional-order PI controller is designed in this work for the outer DC-voltage loop. The proposed FOPI controller provides enhanced robustness and improved damping of double-frequency voltage oscillations under unbalanced grid voltage conditions. To check the effectiveness of the proposed method, a simulation study was carried out for unbalanced grid voltage and grid frequency variation operating conditions.

KEYWORDS:FOPI, FREQUENCY, PLL, BUCK RECTIFIER, GRIDS.

I.INTRODUCTION: The three-phase greenback rectifier (3ph-BR) has garnered numerous interest because to its harmony strength element and splendid dependability [1], [2], [3]. The 3ph-BR's excessive dependability has caused its application in some of industries, such as statistics facilities and telecommunication [4], [5], electric vehicle chargers [6], and more electric powered plane (MEA) [7], [8]. Designing the control method for the 3ph-BR is tough for the reason that grid frequency of the electrical machine inside the MEA commonly modifications in a large variety of 360–800 Hz, mainly while the grid voltages are imbalanced. Asymmetric transmission impedance, single-section hundreds, and grid faults generally bring about unbalanced grid voltages, which cause the 3ph-BR to display erratic output voltage and distorted grid currents [9]. In order to enhance the 3ph-BR's overall performance under unbalanced grid voltages, a number of manage solutions had been put forth. Three special kinds of manipulate strategies exist based on the control objective: balanced input modern control, consistent energetic strength manipulate, and consistent reactive strength manipulate. It is feasible to gain the favored output voltage for the burden via using consistent lively energy manage [10], [11], and [12]. However, a substantially excessive grid imbalance ought to end result from the non-stop active electricity control. In order to reap team spirit energy element and prevent grid imbalance from getting worse, continual reactive energy law is used. The output voltage, but, varies plenty. The switches can enjoy the equal cutting-edge strain thanks to the balanced enter contemporary law. However, there are fluctuations in both the reactive and lively powers.

The aforementioned manage schemes are supposed to reap a single control purpose, even though they can beautify the 3ph-BR's performance beneath imbalanced grid voltages. In exercise, it's far regularly essential to accomplish numerous control objectives in accordance at the load, converters, and grid requirements. As the various control objectives show off unique performances in phrases of the balance of input currents and the ripple of output voltage, the special manipulate need to be implemented in keeping with the precise restrictions. Furthermore, the control targets have to be changed to account for the sort of grid faults. A multifaceted, generalized manipulate approach is required for all of these necessities. Different bendy strength manipulate solutions had been supplied for 3-section pulse width modulation (PWM) converters under an imbalanced grid with the intention to accomplish extraordinary manipulate targets. The bendy power manage approach distributes oscillating power in a pliable manner by way of constructing suitable input cutting-edge references. Therefore, it's miles important to talk approximately the present references production approach due to the fact it is a important set of rules. The segment-locked loop (PLL) and rotating coordinate transformation are typically required to extract superb and bad series grid voltages. For example, the twin 2d-order generalized integrator (SOGI)-based totally PLL (DSOGI-PLL) is used to extract fantastic and bad collection voltages. Comparable manipulate methods are cautioned.

Sequence components are extracted using multiple complex-coefficient-filter PLL and SOGI-frequency-locked loop, respectively, in place of DSOGI-PLL. Using the artificial voltage, which lags 90° from its original grid, is another way to create the current references. Sequence extraction and PLL are not necessary for this approach to function. To obtain the fictional voltage, however, some controllers—such as SOGI and extended state observer (ESO)—remain necessary. These techniques can all effectively create the required current references. However, they are typically used in applications where the grid frequency is fixed. Because the controllers in these strategies—like SOGI and ESO—need to know the grid frequency beforehand, they are not appropriate for applications where the grid frequency fluctuates widely (for example, from 400 Hz to 800 Hz) because the PLL takes time to detect phase and frequency. The input current may be distorted and the system may become unstable throughout the detecting phase.

II.LITARATURE SURVEY:

1) An improved three-phase buck rectifier topology with reduced voltage stress on transistors

Applications requiring a voltage step-down characteristic can enjoy the 3-phase buck rectifier (3ph-BR). To lessen the voltage pressure at the transistors, more advantageous 3ph-BR architecture is usually recommended on this research. In the traditional topology, the freewheeling diode is divided into diodes related in series, with the enter impartial factor being linked to the two diodes' not unusual factor. The transistors simplest should undergo the input segment voltage in place of the road-to-line voltage with the suggested topology and related progressed modulation technique, which considerably reduces voltage strain. A extra flexible and not pricey desire of transistors is made possible by way of the counseled structure. The correctness of the modified topology and associated modulation method has been showed via experimental consequences.

2) An improved three-phase buck rectifier with low voltage stress on switching devices

This letter proposes an more desirable three-section dollar rectifier (3ph-BR) with minimum voltage strain on switching additives. The voltage stress on MOSFETs in the conventional 3ph-BR is greater than the input section voltage amplitude. Nevertheless, the voltage pressure on MOSFETs within the recommended 3ph-BR is much less than the enter phase voltage's amplitude, which reduces the voltage stress on MOSFETs. Thus, the cautioned 3ph-BR is appropriate for applications that demand high-efficiency and excessive-density since low-fee, low-voltage score MOSFETs with low on-resistance can be used. To verify the analysis findings, a 1.5-kW experimental prototype of the recommended rectifier is built.

3) An optimized asymmetric modulation scheme for three-phase buck rectifier without input current distortion at the sector boundaries

A 3-phase buck rectifier normally uses space vector pulse width modulation (SVPWM) to gain minimal switching losses and overall harmonic distortion (THD). The input currents of the three-section greenback rectifier are distorted for the duration of the shift from even to extraordinary sector when the traditional SVPWM scheme is used, which deteriorates the input contemporary harmonics. This letter proposes an uneven modulation technique to cast off the three-section greenback rectifier's enter current distortion for the duration of the even-to-ordinary-zone transition. Two forms of traditional asymmetric modulations in numerous sectors are blended in the cautioned modulation gadget. For in addition electric powered aircraft applications, a 1.5 kW experimental prototype of a three-section dollar rectifier with an ac enter voltage of 115 V/400 Hz is constructed. According to the experimental findings, the three-segment dollar rectifier may also reap a THD of 1.3%.

III.PROPOSED SYSTEM: Fig. 1 illustrates the schematic of the 3ph-BR power converter, which utilized to convert three-phase AC grid power into a stepped-down DC voltage for a load. The system is primarily composed of the utility grid, the 3ph-BR converter, input- and output-side LCL filter units, and the load.

On the input side, the grid may experience voltage unbalance during faults or varying load conditions. The input filter facilitates the reduction of switching harmonics, input current harmonics, and high-frequency disturbances from the grid. The 3ph-BRconverter consists of controlled power semiconductor switches with anti-parallel diodes. This rectifier performs AC–DC conversion while stepping down the voltage level. By controlling the switching of these devices, the rectifier draws controlled, nearly sinusoidal currents from the grid.

On the output side, an output filter is used to supress the harmonics in the rectified voltage and reduces the ripple caused by switching. Therefore, a balanced and stable DC voltage is supplied to the load. The 3ph-BR converter is controlled by a FOPI controller, where voltage and current feedback signals are used to generate appropriate switching commands. Compared to a conventional PI controller, the FOPI controller improves voltage regulation, disturbance rejection, and robustness under unbalanced and variable grid conditions, thereby enhancing the overall performance of the 3ph-BR converter.

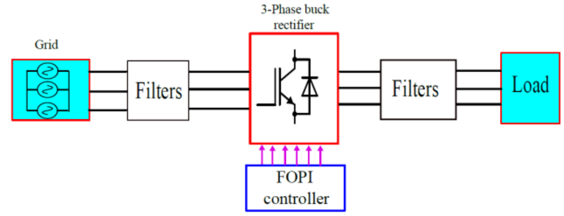


Fig.1 Circuit topology of FOPI control scheme based 3-ph BR converter.

Proposed method:

To enhance transient performance of the 3ph-BR when operating under unbalanced grid voltage and wide grid-frequency conditions, a FOPI controller is implemented in this work for the outer DC-link voltage control loop. Unlike standard PI controllers, the FOPI controller replaces the integer-order integrator with a fractional-order integrator. This provides more control freedom, thus offering additional flexibility in shaping the system’s dynamic response.

The transfer function of the FOPI controller is mathematically given as:

$$G_{FOPI}(s) = K_p + \frac{K_i}{s^{\mu}};\ 0 < \mu < 1$$

where μ represents the fractional order of integration. The μ value typically selected between 0 and 1.

The voltage error signal is defined as:

$$e_v(t) = V_o^* - V_o(t)$$

where $V_o^*$is the reference DC output voltage and $V_o(t)$is the measured DC output voltage. The output of the FOPI controller, denoted as $k_v(t)$, is obtained as

$$k_v(t) = K_p e_v(t) + K_i\, D^{-\mu}\{e_v(t)\}$$

where $D^{-\mu}\{\cdot\}$represents the fractional-order integral operator.

The controller output $k_v(t)$ acts as a power-scaling factor in the proposed power-following control scheme. The input active power drawn from the grid in the stationary reference frame is given by

$$P(t) = \frac{3}{2}\left(v_\alpha(t) i_\alpha^*(t) + v_\beta(t) i_\beta^*(t)\right)$$

To ensure power balance between the AC and DC sides, the reference inductor current magnitude is generated as

$$i_L^*(t) = k_v(t)\left(v_\alpha(t) i_\alpha^*(t) + v_\beta(t) i_\beta^*(t)\right)$$

Thus, the FOPI controller indirectly regulates the input power flow to maintain the DC-link voltage at its reference value.

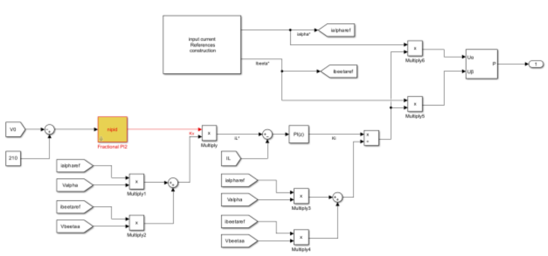


Fig.2 Proposed FOPI control scheme for 3ph-BR power converter.

This study proposes a novel flexible power control for 3ph-BR to accomplish many control objectives in the application with wide grid frequency variation. Analysis is done on the fluctuating power distributions and the performances that go along with them. It allows for variable power control by adjusting a parameter to control the oscillating power. Furthermore, a better current reference construction method is suggested and contrasted with the traditional approach. The suggested technique, which is appropriate for applications with large grid frequency variation, just requires amplitude detection of the grid voltages and some computation in place of PLL and SOGI.

IV.SIMULATION RESULTS:

Fig. 3 illustrates the MATLAB/Simulink structure of the proposed FOPI-based 3-ph BR power converter. To investigate the efficacy of the proposed control scheme, the system's performance was analyzed under unbalanced grid voltages and grid frequency varying operating conditions. The proposed FOPI controller operate the 3-ph BR converter precisely and stabilize the DC link voltage at a constant level.

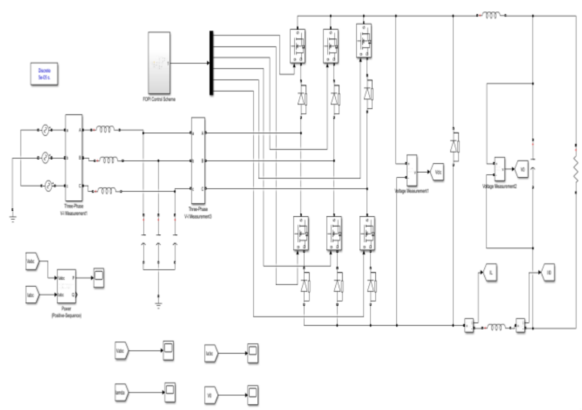
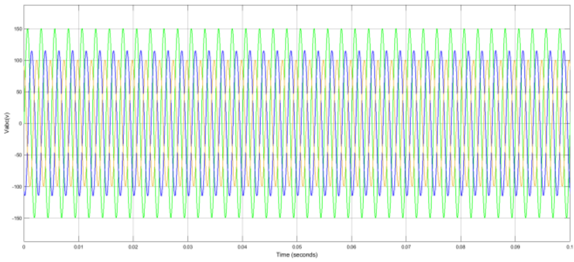
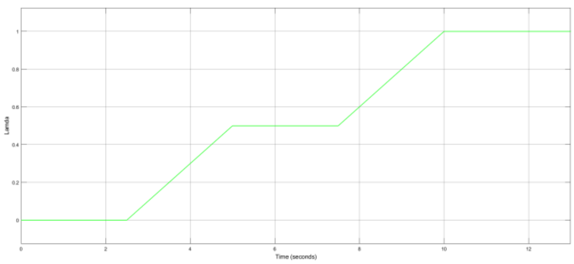
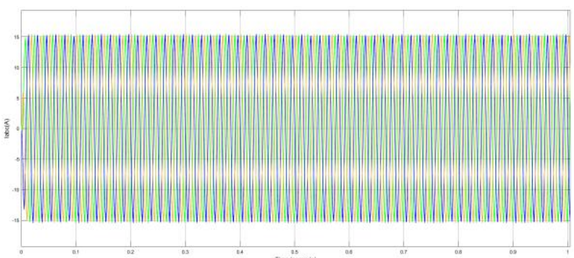
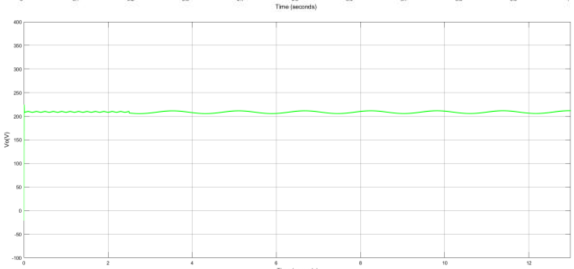


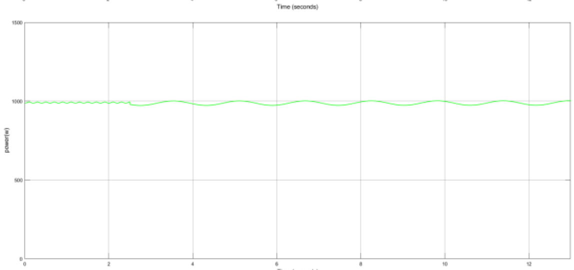
Fig.3 MATLAB circuit layout of FOPI control scheme based 3-ph BR converter.



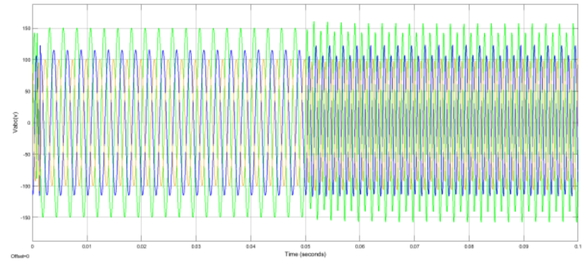


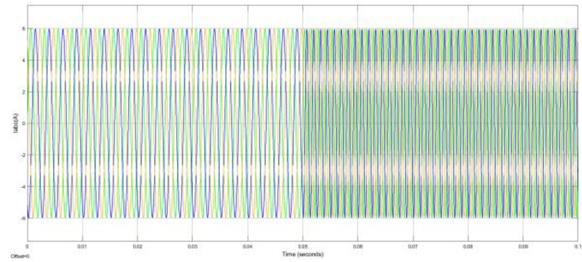


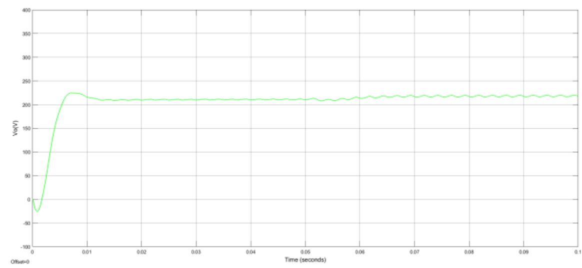




Case2

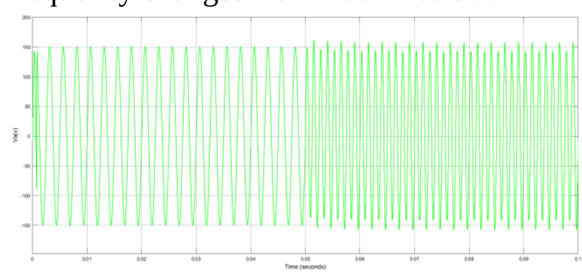


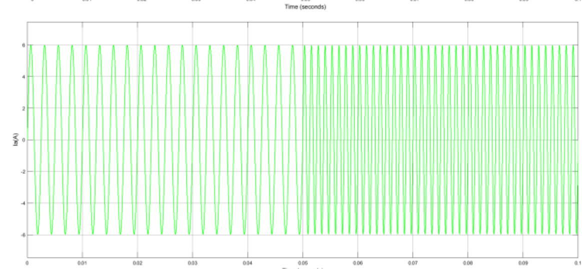




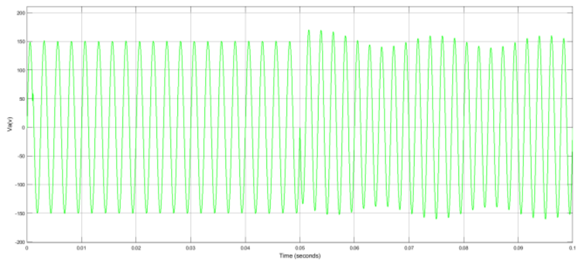
Case 3

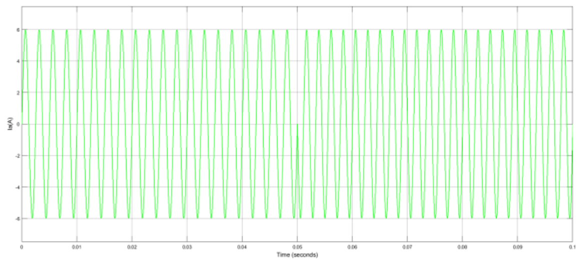
frequency changes from 400 hz to 800hz





Case 4 400hz to 450 hz





IV.CONCLUSION: In this paper discussed the modelling of FOPI control strategy for effective operation of the 3-ph BR power converter. By implementing the FOPI controller in the outer DC-voltage loop, the system achieves enhanced robustness and superior damping of double-frequency voltage oscillations, significantly reducing its sensitivity to grid-induced disturbances. This ensures highly stable DC-link voltage regulation even under severe unbalanced grid conditions. Furthermore, the simulation results validate that the flexible power control strategy seamlessly manages oscillating power distribution. From the simulation outcomes, it is confirmed that the proposed method facilitates a smooth transition between constant active power control, balanced input currents, and constant reactive power control without compromising overall system stability. The proposed method is highly recommended for dynamic applications demanding low DC voltage, such as electric vehicles and more electric aircraft.

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