THD Reduction Comparison of Three Phase SPPS via Conventional RC and Novel PRESH Controller

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Abstract. The proposed paper aims to analysis the THD (Total Harmonic Distortion) of three phase SPPS (Solar Photovoltaic Power System) and a comparison on THD analysis is done via Conventional RC (Resonant Current) and designed Novel PRESH (PRES+RESH) Controller. Presently, for eliminating the harmonic from three phase SPPS, various filters and controller were already proposed but it either resulted in having THD on higher side or made the system bulky. These techniques get fails in eliminating the harmonic when reference waveform get distorted from its original position. The Novel PRESH Controller proposed here is the combination of PRES (Proportional Resonant) and RESH (Resonant Harmonic) controller where inverter current is used as input to compensator of lower forward gain instead of applying the difference of reference current signal and grid current as that in conventional RC controller. Proposed controller can also overcome the problem of distorted reference waveform. An Experimental Setup is designed for investigating Novel PRESH controller in term of THD mitigation and a comparison is done with the conventional RC controller with the help of BP (Bode Plot) to show that proposed Novel PRESH controller can tackle the distorted reference waveform in a reliable manner. Further, to show that THD obtained through the help of Novel PRESH Controller is much lower than that of conventional RC controller and under limit as defined through IEEE standard 519 and.

Keywords: SPPS, PRESH, PRES, RESH, THD, RC.

1 Introduction

Solar Photovoltaic Power System (SPPS) can be connected to grid using converter [1]-[8]. The converter used here will ensure flow of power from SPPS to grid. SPPS can also be connected with other local load, energy storage [9]-[12]. The power quality of grid mainly depends upon voltage, frequency, harmonic, etc [12]-[15]. In order to have good power-factor and minimum line losses the harmonic content of grid connected solar photovoltaic system should be as low as to 1%. Photo-Voltaic system should have low current harmonic distortion so that all other equipment connected to grid do not face any adverse effects. Acc. to IEEE standard 519 and 1547, THD (Total Harmonic Distortion) is kept below 5% [16]. Generally, for reducing current harmonic of SPPS, earlier technique developed are through: lead-lag [17], modified PI [18]-[19], repetitive

[20]-[21], dead-beat [22], PR controller [23]-[25], shunt filter [26]-[30], PRES Controller [31]-[36]. Common technique adopted before for eliminating harmonics among researcher was to make use of resonant current controller [23]-[24]. This controller makes use of proportional resonant and resonant compensator. The function of duo is to keep track of fundamental reference current signal and for attenuating the current harmonics. With normal condition, this controller as referred in reference [24]-[25] work perfectly, but when abnormal condition arises, this compensator performance deteriorates resulting in increase of current harmonic distortion. The simplest technique for eliminating the current harmonic is by engaging the PRES [31]-[36] because of its modularity. In PRES controller, K_P (Proportional gain) is added with resonant path which is set at desired frequency. Several advanced techniques for mitigating the harmonic have been discussed in details [37]-[42]. These control techniques make use of separately generated current reference by the help of positive and negative sequence component. Phase locked loop Algorithm as discussed in [31] and [40]-[41] does not get affect from the voltage harmonic, inter-harmonic and imbalance conditions. But these control techniques are complex and have high computational loading problem. The alternative for these techniques is achieved through [43]-[45] where Resonant Harmonic Controller is incorporated in series with Proportional resonant controller.

The presented paper at first will discuss the design procedure of Novel PRESH controller along with its implementation in grid tied SPPS. In second step, a comparison is done in THD reduction for three phase SPPS via conventional RC and Novel PRESH controller. For eliminating the higher order harmonic, Novel PRESH controller make use of PRES controller which is connected in parallel with RESH controller instead of conventional series connection as discussed in [42]-[43]. The analysis of Conventional RC and Novel PRESH controller is done through the help of bode plot analysis.

Novelty and Originality of the proposed research paper are as:

- Earlier technique develops for reducing current harmonics among researcher were lag-lead controller [17], modified PI controller [18]-[19], repetitive controller [20]-[21], dead beat controller [22], PR controller [23]-[25], shunt filter [26]-[30], suffer certain drawback as indicated:
- Standard PI controller, can't track ac current reference.
- [18]-[19], shows very poor response in tracking sinusoidal reference as well as while rejecting the disturbances.
- [23]-[25] can't use with present day Grid Connection as there is need of digital implementation of controller for rejecting the harmonic.
- [26]-[30] Elimination of harmonic through the use of shunt filter becomes an old technique as their inability in eliminating the harmonic as per IEEE reference 519 and 1547.
- Design algorithm of Novel PRESH (Proportional Resonant Harmonic) controller is discussed where inverter current is used as input to compensator of lower forward gain instead of applying the difference of reference current signal and grid current as that in conventional RC controller.
- Comparison between Conventional RC and designed Novel PRESH controller is done in term of THD mitigation, to show that designed Novel PRESH controller can tackle even if reference waveform is distorted one and also to show that THD obtained by Novel PRESH controller is far less than conventional RC controller.

The proposed paper is carved out in the following manner: Section II will discuss about three phase grid tied solar photovoltaic power system (SPPS), Section III will deal with design algorithm of Novel PRESH controller, Section IV will deal with THD analysis of Novel PRESH controller in term of Bode-Plot analysis and harmonic mitigation followed by conclusion.

2 Three Phase SPPS

Fig.1 represent the three phase SPPS having Photovoltaic module/array, a capacitor C_{dc} and a 3- phase voltage source inverter connected with three phase grid having voltages as V_{ga}, V_{gb} and V_{gc}.

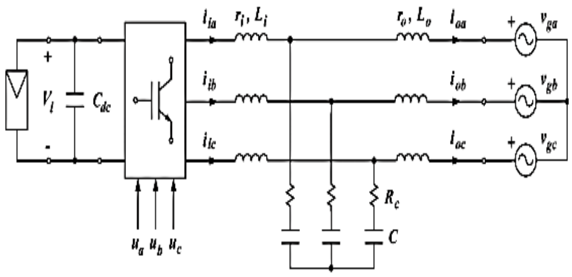


Fig.1 Three Phase Solar Photovoltaic Power System (SPPS)

For reducing the high frequency switching harmonic, L-C-L filter is employed and for attenuating the peak magnitude of L-C-L filter at resonance frequency and damping resistor is made to connect in series with capacitor.

2.1 Open loop Mode (OLM)l of 3-phase SPPS

Average model of 3-phase SPPS is shown by below Fig.

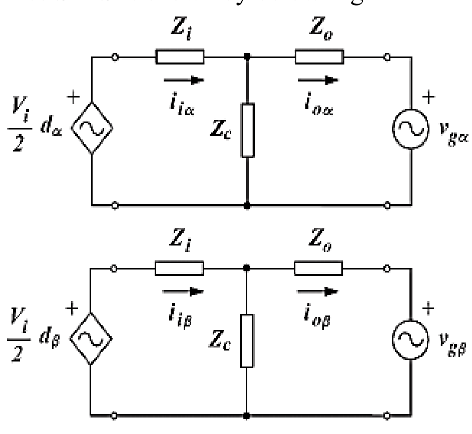


Fig. 2 Average circuit Model (ACM) of three phase grid tied SPP

Input to this model is V_i which is a dc link voltage, grid voltage is denoted as V_g and control input d whose value varies from -1 to +1.

$$-1 \leq d_\alpha \leq +1 \quad (1)$$

$$-1 \leq d\beta \leq +1 \quad (2)$$

Inverter current is indicated by i_i whereas grid current is indicated by i_o.

3 DESIGNING OF NOVEL PRESH CONTROLLER

3.1 Conventional RC controller in three phase SPPS

Fig. 3 shows a Conventional RC controller. Where, $H_1(s)$ is PRES (Proportional Resonant) controller and $H_2(s)$ is RESH (Resonant Harmonic) Controller.

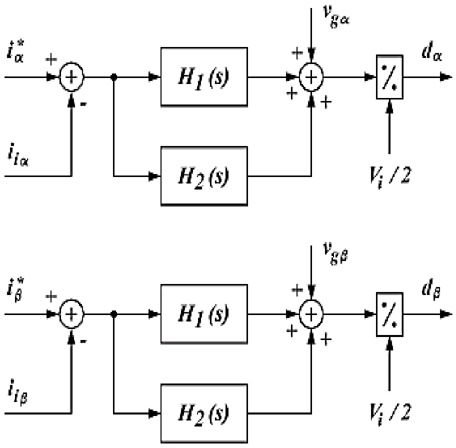


Fig. 3 Conventional RC controller

The difference of input current and reference current i.e error is processed through proportional controller and resonant controller. Generally, inverter current is used in place of grid current so as to increase the robustness of the system and to reduce the requirement of current sensor. Dc link voltage and voltage of grid are used here as a forwarded signal so as to improve the system dynamic. By engaging this forwarded signal, system capability in rejecting external disturbances also gets enhanced [47].

Following equation can be derived from Fig. 3 as:

$$d_\alpha = \frac{2}{V_i}\left[v_{g\alpha} + (H_1(s) + H_2(s))\,(i_\alpha^* - i_{i\alpha})\right] H_d(s) \quad (3)$$

$$d_\beta = \frac{2}{V_i}\left[v_{g\beta} + (H_1(s) + H_2(s))\,(i_\beta^* - i_{i\beta})\right] H_d(s). \quad (4)$$

Here, d_α, d_β are the control input which can take value from -1 to +1, and V_g is the voltage of grid and $H_d(s)$ is transfer function of model having time delay as T_d.

For control processing time delay T_d, transfer function is given as

$$H_d(s) = e^{-T_d s}. \tag{5}$$

The parameter used in the transfer function of above compensator is shown by Table 1, along with list of value used in the work. Table 1 also contain the detail parameter of three phase SPPS used here.

Table 1. Parameters of Three Phase SPPS

Symbol	Quantity	Nominal Value
P_m	Maximum output power	3.2 KW
f_i	Switching frequency	10 KHz
$V_{i, OC}$	Open Circuit PV array output Voltage	750 V
$I_{i, SC}$	Short circuit PV array output current	5.4 A
$V_{i, MP}$	Maximum power PV output voltage	650 V
$I_{i, MP}$	Maximum Power PV output current	4.9 A
L_i	Inverter side Inductance	6.9 mH
R_i	Inverter side resistance	0.27 Ω
C	Filter Capacitor	680 nF
R_c	Filter damping resistance	6.8 Ω
L_o	Grid side inductance	2.1 mH
R_o	Grid side resistance	0.14 Ω
V_g	Grid Voltage (rms, phase to neutral)	200 V
f_o	Grid frequency	50 Hz
K_p	Proportional gain	60 Ω
K_{i1}	Fundamental integral gain	300 Ω s^2
K_{in}	n-harmonic integral gain	300 Ω s^2
ϵ_1	Fundamental damping factor	0.01
ϵn	n-harmonics damping factor	0.01
N	Selected harmonics to be attenuated	5,7,11,13
T_d	Control Processing delay time	100 µs

4 Novel PRESH in Three Phase SPPS

4.1 1st step: Design Control Configuration of Novel PRESH controller

In this Novel PRESH controller, shown by Fig. 4, inverter current is used as input to compensator of lower forward gain instead of applying the difference of reference current signal and grid current.

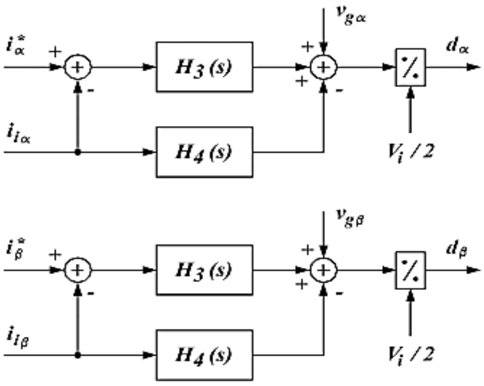


Fig. 4 Proposed PRESH Controller

Transfer functions of PRESH controller are obtained as:

$$H_3(s) = \frac{k_{i1} 2\xi_1 \omega_o s}{s^2 + 2\xi_1 \omega_o s + \omega_o^2} \tag{6}$$

$$H_4(s) = k_p + \sum_n \frac{k_{in} 2\xi_n (n\omega_o) s}{s^2 + 2\xi_n (n\omega_o) s + (n\omega_o)^2}. \tag{7}$$

4.2 2nd step: Closed-Loop Transfer Function of Novel PRESH controller

From Fig. 4, control input of Novel PRESH controller can be written as

$$d_\alpha = \frac{2}{V_i}\left[v_{g\alpha} + H_3(s)\left(i_\alpha^* - i_{i\alpha}\right) - H_4(s) i_{i\alpha}\right] H_d(s) \tag{8}$$

$$d_\beta = \frac{2}{V_i}\left[v_{g\beta} + H_3(s)\left(i_\beta^* - i_{i\beta}\right) - H_4(s) i_{i\beta}\right] H_d(s). \tag{9}$$

By substituting equation (8) and (9) in Fig. 2 so as to obtain closed loop transfer function of Novel PRESH controller, we get:

$$T(s) = \left(Z_c(s) + Z_o(s)\right) G_i(s) \left(H_3(s) + H_4(s)\right) \times H_d(s) \tag{10}$$

$$G_r(s) = \frac{Z_c(s) G_i(s) H_3(s) H_d(s)}{1 + T(s)} \tag{11}$$

$$G_g(s) = -\frac{G_i(s)\left(Z_i(s) + \left(H_3(s) + H_4(s)\right) H_d(s)\right)}{1 + T(s)}. \tag{12}$$

5 ANALYSIS OF NOVEL PRESH CONTROLLER

5.1 Bode Plot Analysis of Novel PRESH Controller

Bode Plot figure of PRES and RESH controller used in proposed PRESH Controller is indicated by Fig. 5.

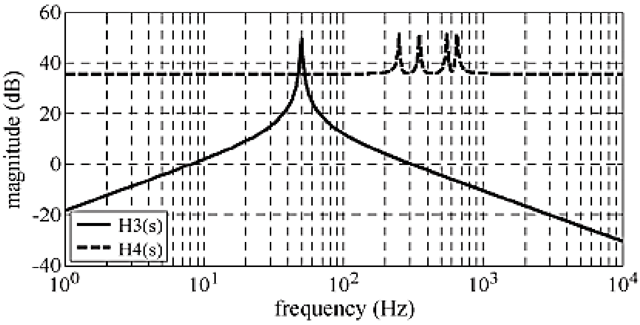
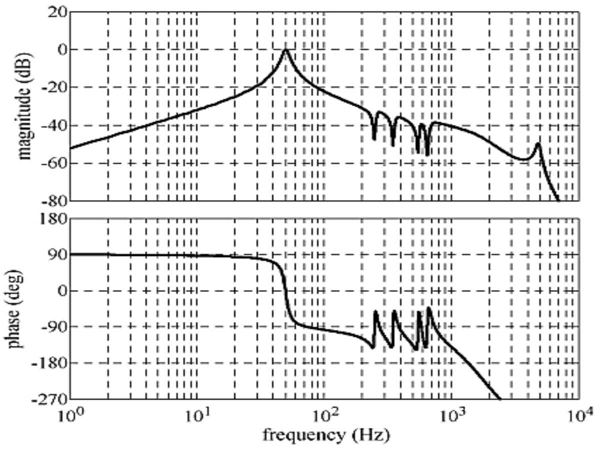


Fig. 5. BP figure of PRES & RESH Controller used in Proposed Novel PRESH controller

Bode-Plot of transfer function for proposed Novel PRESH controller is indicated by Fig. 6. All the value taken for case study of Novel PRESH controller is indicated in table 1.

Fig. 6. Bode-Plot figure of Novel PRESH controller



From the above figure it is clear that, transfer function of proposed Novel PRESH controller has behavior similar to band pass filter. At, selected harmonic frequency i.e 250, 350, 550 and 650 Hz, dip in magnitude diagram can be seen. Thus, by using this proposed Novel PRESH controller, tracking of fundamental component of signal can be expected even if reference waveform is distorted one.

5.2 THD Analysis of PRES Controller in three phase SPPS

Experimental Setup of 3-Phase GTSPPS for testing of proposed PRESH Controller is shown by Fig. 7.

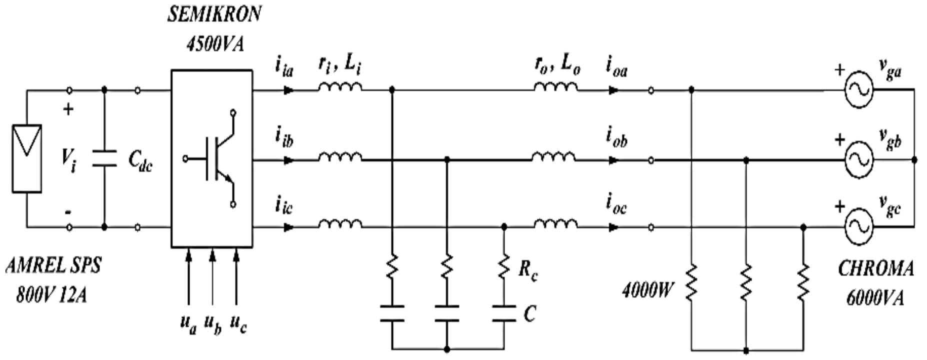


Fig. 7 Experimental set up of three phase SPPS for Novel PRESH controller testing

It makes use of dc source connected with PV array, an inverter, programmable chroma and others. Here load taken is 4KW resistive in nature. This load presence is mandatory in the proposed experimental setup as ac source can't absorb the active power injected.

Further, it also includes standard external control loop and internal control loop along with modulator represented by Fig. 8 and Fig. 9 respectively.

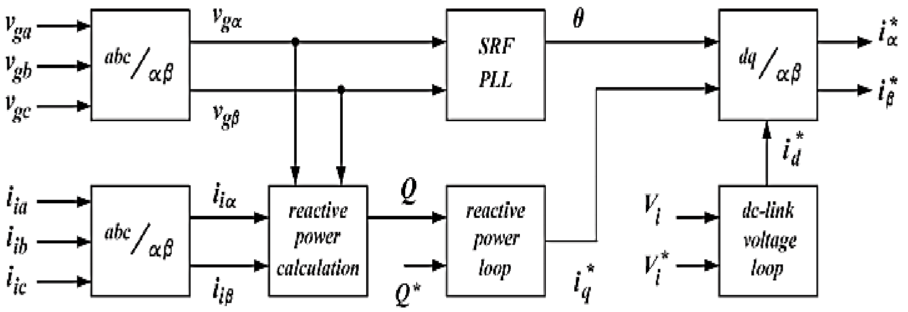


Fig. 8 External Control Loop

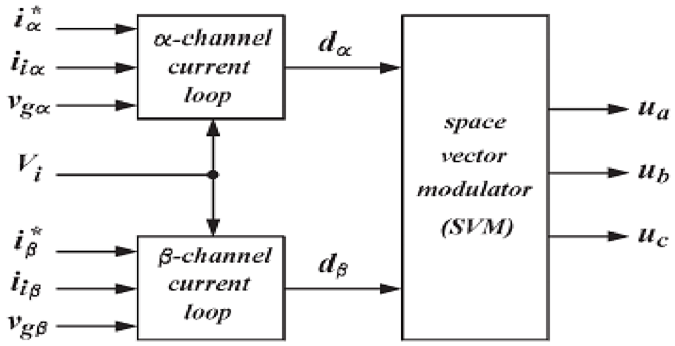
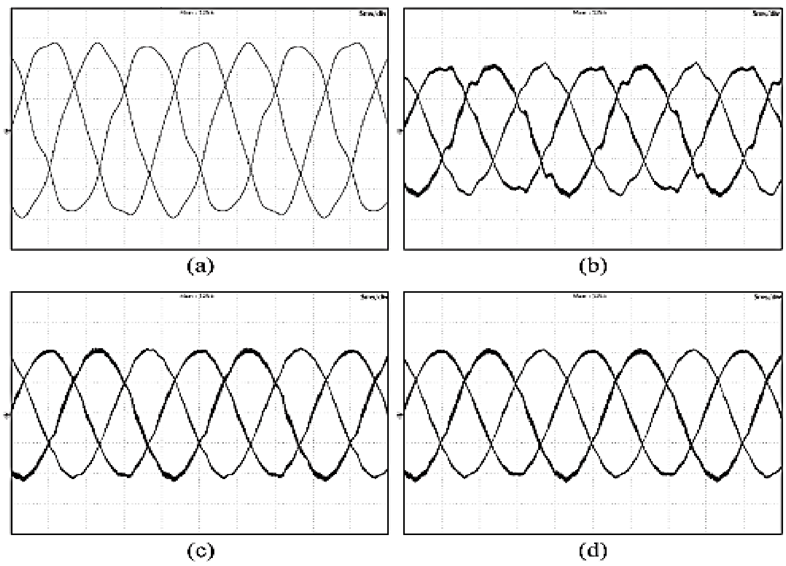


Fig. 9 Internal Control Loop

The proposed novel PRESH Controller of this paper is tested with high voltage disturbances of the grid and the waveform of various parameter used is shown by Fig. 10.

Fig. 10 Simulation result for grid condition with high voltage THD (a) Grid Voltage (b)



Standard Control without Resonant Harmonic Controller (c) Standard Control with Resonant Harmonic Controller (d) Proposed Novel PRESH Controller

Harmonic distortion thus calculated is depicted by table 2 comparing the THD without controller and with proposed controller of the system.

From table 2, it is cleared that standard control gives very poor performance when resonant harmonic controller is not engaged however, the performance improves a bit after engaging the resonant harmonic controller.

The Proposed Novel PRESH controller reduces the current harmonic distortion well below to 5% which is as per IEEE standard 519 and 1547.

Table 2: THD under different control technique

Control Technique	V_{ga}	V_{gb}	V_{gc}	I_{oa}	I_{ob}	I_{oc}
Conventional control without Resonant Harmonic Controller	4.0	4.5	7.5	3.6	3.4	5.7
Conventional control with Resonant Harmonic Controller	3.7	4.7	7.8	1.8	1.8	2.3
Novel PRESH Controller	3.8	4.8	7.8	0.9	0.92	0.945

From table 2, it is cleared that standard control gives very poor performance when resonant harmonic controller is not engaged however, the performance improves a bit after engaging the resonant harmonic controller.

The Proposed Novel PRESH controller reduces the current harmonic distortion well below to 5% which is as per IEEE standard 519 and 1547.

Conclusions

The presented paper discusses the design algorithm and performance anlaysis in term of THD and harmonic mitigation along with bode plot analysis of Novel PRESH (PRES+RESH) controller Interfaced with three phase SPPS (Solar Photovoltaic Power System).

Implementation of Phase Locked Loop is done in an effective manner, for synchronizing the SPPS with grid voltage. Further, identification of indirect mechanism is done that was responsible in generating the current harmonic from abnormal grid condition in standard resonant current controller. The proposed Novel PRESH controller overcome this problem by connecting in a different configuration as explained by using case study. Thus, able to track the fundamental component even if abnormal condition arises.

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