Harmonic Mitigation In Grid-Tied TPSPPS Via Novel PRESH Controller

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Abstract— The proposed paper deals with a new type of controller credited with a name of "Novel PRESH" helpful in mitigating the harmonic of Grid Tied TPSPPS (Grid-Tied Three Phase Solar Photovoltaic Power System) even during abnormal grid condition. Novel PRESH controller is formed by combining the characteristic of PRES and RESH Controller and its harmonic mitigation analysis is done with the help of both Bode-Plot and MATLAB Simulink. Presently, for eliminating the harmonic from Grid -Tied TPSPPS, various filters and controllers have already been proposed but it either resulted in increase of computational load or make the system bulky. Earlier technique develops in eliminating the harmonic face difficulty in eliminating the harmonic when the reference waveform get distorted from its original position. The proposed "Novel PRESH" controller can also be incorporated when grid suffers from any abnormal condition. The presented paper will also discuss the performance analysis of controller along with its design procedure that are helpful in mitigating the THD of three phase SPPS near to 1% and thus satisfying the IEEE standard 519 and 1547.

Keywords—GTSPPS, PRES, PRESH, RESH, THD.

I. 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]-[11]. The power quality of grid mainly depends upon voltage, frequency, harmonic, etc [12]-[14]. 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 equipments connected to grid do not face any adverse effects. Acc. to IEEE standard 519 and 1547, THD (Total Harmonic Distortion) is kept below 5% [15]. Generally, for reducing current harmonic of SPPS, earlier technique developed for eliminating the harmonics are through: lead-lag [16], modified PI [17]-[18], repetitive [19]-[20], dead-beat [21], PR controller [22]-[24], shunt filter [25]-[29], PRES Controller [30]-[35].

Common technique adopted before for eliminating harmonics among researcher was to make use of resonant current controller [22]-[23]. 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 [23]-[24] 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 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 [36]-[41]. 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 [30] and [39]-[40] 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 [42]-[44] where Resonant Harmonic Controller is incorporated in series with Proportional resonant controller instead of connecting in parallel configuration.

This paper at first step discuss the design procedure of Novel PRESH controller.

In second step, performance analysis of Novel PRESH controller will be seen. For eliminating the higher order harmonic, PRES compensator is connected in parallel with RESH controller to make a Novel PRESH controller instead of conventional series connection as discussed in [41]-[42]. The analysis of both controller is done through the help of graph along with bode plot analysis.

The main advantage of Novel PRESH controller proposed in this paper is to show that even if reference waveform is distorted one, this controller can tackle it in a very reliable manner and that is one of the originality of this proposed paper.

Novelty and Originality of the proposed research paper are as:
- Earlier technique develop for reducing current harmonics among researcher were lag-lead controller [16], modified PI controller [17]-[18], repetitive controller [19]-[20] , dead beat controller [21], PR controller [22]-[23], shunt filter [24]-[28], suffer certain drawback as indicated:
- Standard PI controller, can't track ac current reference.
- [17]-[18], shows very poor response in tracking sinusoidal reference as well as while rejecting the disturbances.
- [22]-[23] can't use with present day Grid Connection as there is need of digital implementation of controller for rejecting the harmonic.
- 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 PRES controller is connected in parallel with RESH (Resonant Harmonic) controller instead of conventional series connection.
- Performance Analysis of Novel PRESH controller is discussed in term of harmonic mitigation with low computational load as compared to standard controller design.

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 performance analysis of Novel PRESH controller in term of Bode-Plot analysis and harmonic mitigation.

II. GRID-TIED THREE PHASE SPPS

Fig.1 represent the grid-tied 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 Vga, Vgb and Vgc.
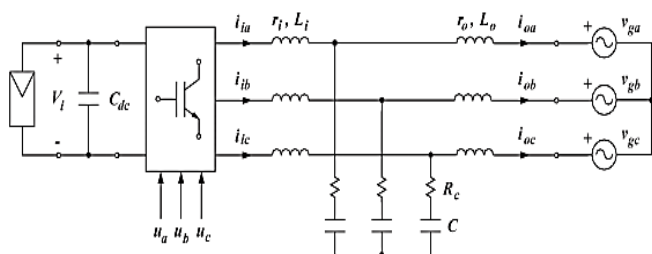

Fig.1 Grid -Tied Three Phase Solar Photovoltaic Power System (TPSPPS)

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.

A. Open loop Mode (OLM) of 3-phase Grid-Tied TPSPPS

Average model of Grid-tied TPSPPS is indicated by Fig. 2. 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.

$$-1 \leq d_\alpha \leq +1 \tag{1}$$

$$-1 \leq d_\beta \leq +1 \tag{2}$$

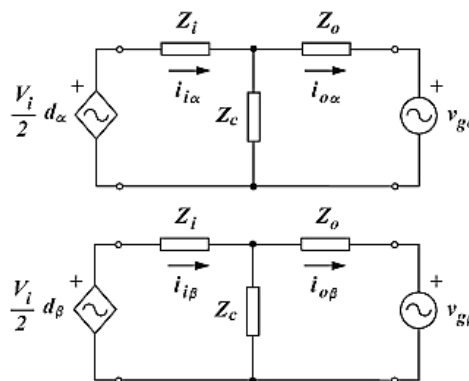Inverter current is denoted by i_i and grid current is denoted by i_o.

Fig. 2 Average circuit Model of Grid -tied 3-phase SPPS

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 grid tied three phase SPPS used here.

Table 1 Parameters of Grid -Tied 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 s²
K_{in}	n-harmonic integral gain	300 Ω s²
ϵ_1	Fundamental damping factor	0.01
ϵ_n	n-harmonics damping factor	0.01
N	Selected harmonics to be attenuated	5,7,11,13
T_d	Control Processing delay time	100 μs

III. DESIGN ALGORITHM OF NOVEL PRESH CONTROLLER

A. Design Procedure of Novel PRESH controller

The main purpose of Novel PRESH controller is to achieve lower current harmonic distortion even if grid current experiences the abnormal conditions.

1st Step: Control Configuration of Novel PRESH controller

In this proposed Novel PRESH controller, shown by Fig. 3, inverter current is used as input to compensator of lower forward gain instead of applying the difference of reference current signal and grid current.
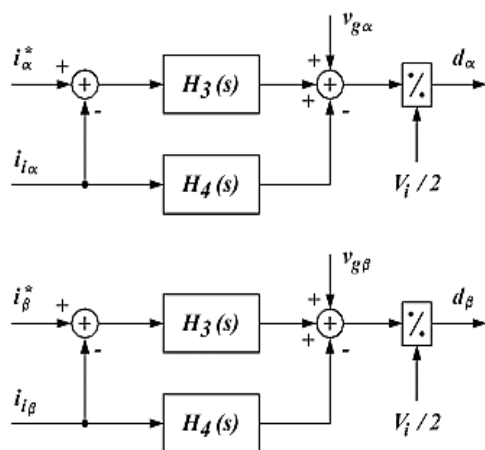

Fig. 3 Proposed Novel PRESH Controller

Where, $H_3(s)$ is PRES (Proportional Resonant) controller and $H_4(s)$ is RESH (Resonant Harmonic) Controller.

Transfer functions of Novel PRESH controller are obtained as:

$$H_3(s) = \frac{k_{i1}2\xi_1\omega_o s}{s^2+2\xi_1\omega_o s+\omega_o^2} \quad (3)$$

$$H_4(s) = k_p + \sum_n \frac{k_{in}2\xi_n(n\omega_o)s}{s^2+2\xi_n(n\omega_o)s+(n\omega_o)^2} \quad (4)$$

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

From Fig. 3, control input of proposed Novel PRESH controller can be written as

$$d_\alpha = \frac{2}{V_i}\left[v_{g\alpha} + H_3(s)(i_\alpha^* - i_{i\alpha}) - H_4(s)i_{i\alpha}\right]H_d(s) \quad (5)$$

$$d_\beta = \frac{2}{V_i}\left[v_{g\beta} + H_3(s)\left(i_\beta^* - i_{i\beta}\right) - H_4(s)i_{i\beta}\right]H_d(s) \quad (6)$$

By substituting equation (5) and (6) in Fig. 2 so as to obtain closed loop transfer function of proposed Novel PRESH controller, we get:

$$T(s) = \left(Z_c(s) + Z_o(s)\right)G_i(s)\left(H_3(s) + H_4(s)\right) \\ \times H_d(s) \quad (7)$$

$$G_r(s) = \frac{Z_c(s)G_i(s)H_3(s)H_d(s)}{1+T(s)} \quad (8)$$

$$G_g(s) = -\frac{G_i(s)\left(Z_i(s)+(H_3(s)+H_4(s))H_d(s)\right)}{1+T(s)} \quad (9)$$

IV. ANALYSIS OF NOVEL PRESH CONTROLLER

A. Bode Plot Analysis of proposed Novel PRESH Controller

Bode Plot figure of PRES and RESH controller used in proposed Novel PRESH Controller is indicated by Fig. 4.
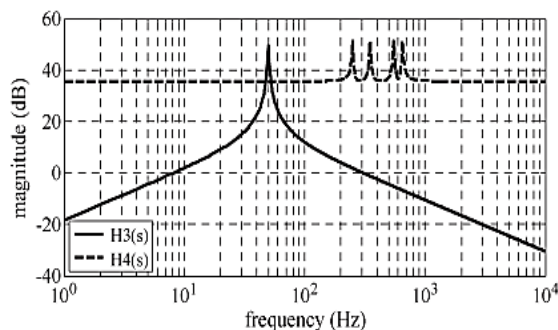

Fig. 4. Bode-Plot figure of PRES and RESH Controller used in Proposed Novel PRESH controller

Bode-Plot of transfer function for proposed Novel PRESH controller is indicated by Fig. 5. All the value taken for case study of Novel PRESH controller is indicated in table 1.
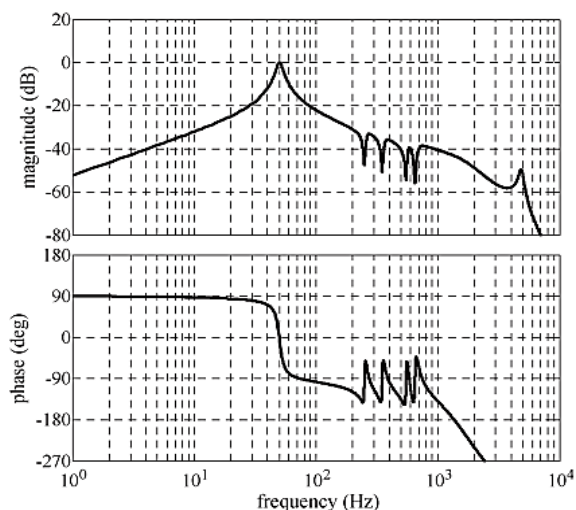

Fig. 5. Bode-Plot figure of proposed Novel PRESH controller

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.

B. Harmonic Analysis of proposed Novel PRESH Controller in three phase SPPS

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. 6.
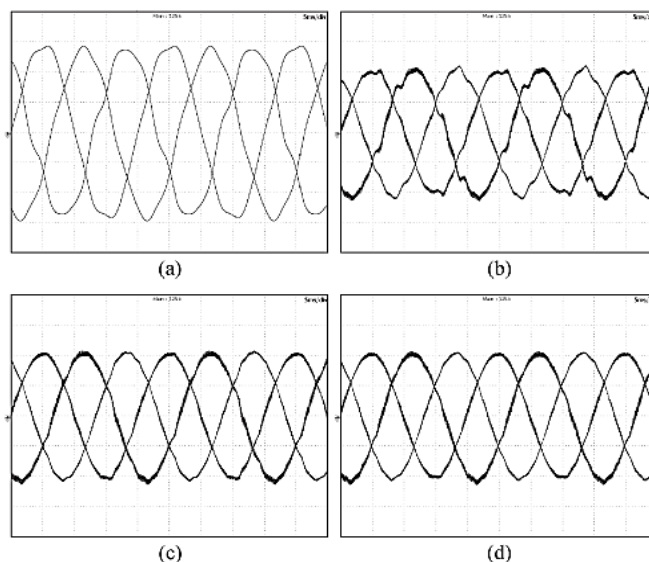

Fig. 6 Simulation result for grid condition with high voltage THD (a) Grid Voltage (b) Standard Control without Resonant Harmonic Controller (c) Standard Control with Resonant Harmonic Controller (d) Proposed Novel PRESH Controller

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

Table 2 THD under different control technique

Control Technique	V_{ga}	V_{gb}	V_{gc}	I_{oa}	I_{ob}	I_{oc}
Standard control without Resonant Harmonic Controller	4.0	4.5	7.5	3.6	3.4	5.7
Standard control with Resonant Harmonic Controller	3,7	4.7	7.8	1.8	1.8	2.3
Proposed Novel PRESH Controller	3.8	4.8	7.8	0.9	0.92	1.12

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.

V. CONCLUSION

The presented paper discuss the design algorithm and performance analysis 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).
Proposed Novel PRESH Controller was also tested with high voltage disturbances of the grid and waveform shows good result.
Further, identification of indirect mechanism is done that was responsible in generating the current harmonic from abnormal

grid condition in standard resonant current controller

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