

Control Plan of Flyback Micro-Inverter with Controllers for PV AC Components

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ABSTRACT: In this thesis, we control the output of flyback micro inverter with controllers. The suggested control plan involves two components. The proportional-resonant controller (PR) with the harmonic compensator and hybrid nominal duty ratio Associated to the conventional control plan using the proportional-integral controller (PI). The proportional-resonant controller with the harmonic compensator brings higher system gain without using high proportional gain in two modes. It delivers high system gain at the fundamental and harmonic frequencies of the grid. Then it enriches the tracking speed, and disturbance rejection performance is satisfying the desired stability. In the suggested control plan hybrid nominal duty ratio reduces the disturbance rejections, and also control burden. But the combination of proportional integral controller and second-order low-pass filter gives less total harmonic distortion compared with the suggested one. Finally, the simulation was shown to verify the tracking speed, and disturbance rejection performances of the suggested control plan, and total harmonic distortion was shown to confirm the benefits of the combination of Proportional integral controller and second-order filter.

KEYWORDS: Index Terms-System gain, tracking speed, disturbance rejection, total harmonic distortion, PV module.

I.INTRODUCTION

Renewable energy generates from renewable energy resources. It is a natural process, and also it is naturally replenished on a human period, such as sunlight, rain, wind, waves, tides, and geothermal heat. Due to the so many advantages of renewable energy sources the PV energy became the part of so many industrial fields. The PV power systems can be categorized into centralized, AC, and string module system. Among them in the AC module system, a low-power grid-connected inverter called as the micro-inverter is mounted on single PV module. By PV module mismatch and partial shading, it can reduce the power losses, and also it can track the individual maximum power point. Comparing to centralized, string module systems the ac module system has higher reliability and easier maintenance. The future PV power system is the ac module system because of these advantages. A solar micro-inverter, or simply micro-inverter, is a device used in photovoltaic that converts direct current (DC) generated by a single solar unit to alternating current (AC). The output from several micro-inverters is combined and often fed to the electrical grid. Micro-inverters difference with conventional string and central solar inverters, which are connected to multiple solar units or panels of the PV system. In micro-inverter designs, to perform power conversion on each module each solar panel has its own inverter. Micro-inverter architectures are costlier than the other two, but gives the highest power optimization and design flexibility and also avoid a single point of failure. Micro-inverters that are based on the flyback converter topology.

Below three figures are the central inverter and string inverter and, micro inverter. In central inverter all solar panels are connected to single inverter, in the case of string inverter some set of solar panels are connected to inverter, and in the case of micro-inverter each solar panel having their individual inverter.

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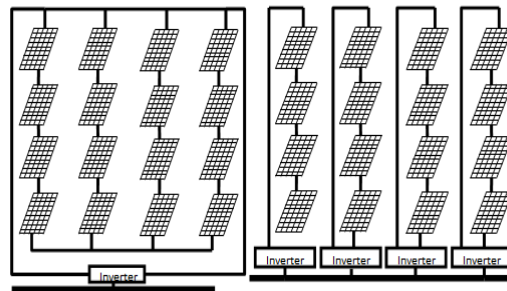


Fig 1. Central Inverter Fig 2. String Inverter

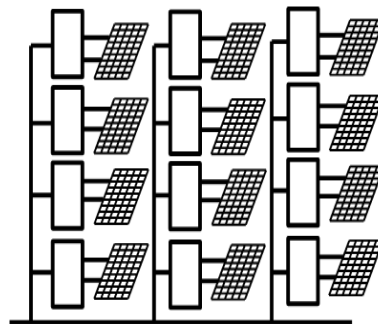


Fig 3. Micro-inverter

The flyback converter is a post-ponement of the Buck-Boost converter. The fly back converter is built by replacing inductor with the transformer in Buck-Boost converter. The flyback converter is used in both alternating currents to direct current and direct current to direct current conversion with galvanic isolation between the input and any outputs. The power conversion efficiency, the shape of output current, power density, reliability, and cost to obtain these advantages, a single stage fly back inverter topology has been adopted. The flyback inverter has simple circuit structure and potential for high efficiency and reliability. The flyback inverter has both the functions. First one is step-up function and, another one is step down function. The main characteristic for the PV applications is the step-down and step-up functions. The various conduction modes in which fly back operated are DCM (Discontinuous Conduction Mode), CCM (Continues Conduction Mode). The flyback inverter operate in discontinues conduction mode at a low level of power to make fewer losses or solar level. At all instantaneous power level, fly back operate in Continues Conduction Mode. For reducing the converter losses, the converter has to operate in continuous conduction mode along with magnetizing mode. When the converter is in CCM, the output current handle becomes tuff. Because the right half plane becomes zero in the transfer function. To make sure to not get into situations like distorted output current, the controller has to apply with the complex control scheme. By these, PV inverters which are cheap are not suitable to work in CCM.

In a whole ac line period the flyback inverter has hybrid operation mode. Compared to a fly back inverter only with DCM, the flyback inverter with hybrid mode has many advantages such as lower current stress, higher efficiency, easier filter design, and higher power capability. However, the limitations of increasing in the system gain and controller band width due to the right half plane zero. This is possible in current transfer function of the flyback inverter in the CCM region. Since the operating point changes broadly in the PV inverter applications, in particular, the controller should cover the minimum RHP zero. In a conventional control plan the proportional integral controller (PI) with flyback inverter in the hybrid mode the proportional gain is designed to be relatively low for ensuring stability in all operating points. The system gain of the fly back inverter in the DCM regions characteristically is much low. In DCM region also for obtaining the fast reference tracking, and disturbance rejection a high-gain feedback controller is

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required. The control gain is limited by the RHP zero in CCM with the conventional PI controller. As a result, it causes unacceptable power quality and high total harmonic distortion (THD) by the poor control performance in DCM. That is the reason why the use of the flyback inverter with conventional control plan is restricted despite its many advantages. But the combination of PI controller with second order filter gives total harmonic distortion to very lesser value compared with PI controller and PR controller. The PR controller means proportional resonant controller.

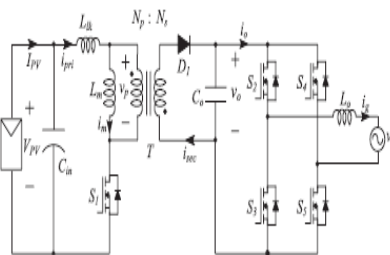


Fig 1. Circuit diagram of the flyback micro-inverter

The PR controller is resonant at the selected frequency. The PR controller is an alternative to the PI controller. The proportional resonant controller (PR) delivers an infinite gain at a selected resonant frequency only without using high proportional gain. The PR controller with the hybrid nominal duty ratio gives faster dynamics, and more effective disturbance rejection. Thus, the suggested control plan gives the better disturbance rejection, and higher tracking performance. In both operation modes the flyback inverter strengthens the many advantages of the flyback with hybrid mode. In the control plan of flyback micro inverter, the current control strategy of the flyback micro-inverter with the hybrid mode is proposed. The suggested control plan consists of two components, the PR controller with the hybrid nominal duty ratio. The PR controller with hybrid nominal duty ratio provides a high gain at the fundamental and harmonic frequencies of the grid and achieves the zero-tracking error in both operation modes. The hybrid nominal duty ratio performs as a feed-forward control input and is determined by the proposed operation mode selection. By applying the hybrid nominal duty ratio according to the proper operation region, it can achieve more effective disturbance rejection and faster dynamics.

II. OPERATION OF THE FLYBACKINVERTER WITH HYBRID MODE

The circuit diagram of the flyback micro-inverter is shown above in Fig 1. It consists of an input capacitor C_{in} , a fly back converter with turn ratio n (N_s/N_p), an output filter, and a full-bridge-type unfolding circuit ($S_2 - S_5$). For the conversion of PV power into the rectified sinusoidal waveform the flyback converter has to operate in high switching frequency. The unfolding circuit ($S_2 - S_5$) works under the grid frequency f . This unfolding circuit operates under grid frequency f to inject sinusoidal AC current into the grid. Switches S_2 and S_5 are turned on during the positive half-cycle of the grid voltage V_g , while S_3 and S_4 are turned on during the negative half-cycle. This figure is equivalent to Buck-Boost converter with inductor split. Therefore, the operating principle of Buck-Boost converter and flyback inverter is same. The switch S is the connection between transformer and voltage source. By closing switch S transformer is directly connected to the voltage source. The storing energy in the transformer is increased by increasing the primary current and magnetic flux in the core. The diode is reverse-biased (i.e., blocked) due to the voltage induced in the secondary winding is negative. The energy flows to the output load with the help of output capacitor. The primary current and magnetic flux decrease when the switch S_1 is open. The secondary voltage is positive, forward-biasing the diode, allowing current to flow from the transformer. The energy from the transformer core recharges the capacitor. The capacitor supplies output to the load. The operation of storing energy in the transformer before transferring to the output of the converter allows the topology to easily generate multiple outputs with little additional circuitry. The transformer turns ratio has to be able to match each other through the output voltage. Also, there is a need

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for a controlling rail which has to be loaded before the load is applied to the uncontrolled rails, this is to allow the PWM to open up and supply enough energy to the transformer.

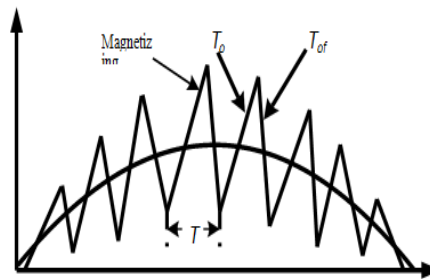


Fig. 2. Continuous conduction mode of magnetizing current

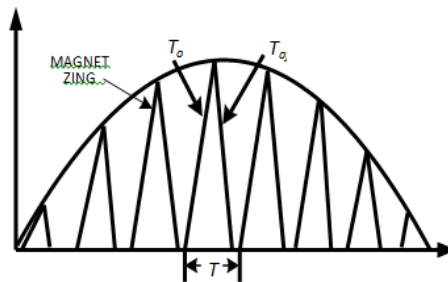


Fig. 3. Discontinuous conduction mode of magnetizing current

Under the constant switching frequency f_s , the operation modes are classified into DCM and CCM. In DCM, the magnetizing current I_m becomes zero within each switching period T_s , and the transformer T is completely demagnetized as shown in Fig. 4. When S1 is turned on, the primary current I_{pri} is stored in the magnetizing inductance L_m , and its peak value is expressed as follows.

$$I_{pri.pk_DCM(t)} = \frac{V_{PV}}{L_m} D_{DCM(t)} T_s$$

Where D_{DCM} is the duty ratio in DCM. The energy E_{Lm} stored in L_m is expressed as

$$E_{Lm} = \frac{1}{2} L_m I_{pri.pk}^2(t) = \frac{(V_{PV} D_{DCM}(t) T_s)^2}{2L_m}$$

Assuming lossless operation in the inverter, the power balance equations can be obtained as

$$V_{PV} I_{PV} = \frac{V_g I_g}{2} = P_o$$

$$V_{PV} I_{Pri}(t) = v_g(t) i_g(t) = V_g I_g \sin^2 \omega t$$

Where V_{pv} and I_{pv} are the average values of the voltage and current for a PV module. V_g and I_g are the grid voltage and grid current, respectively; V_g and I_g are the peak values of v_g and i_g , respectively. P_o is the average output power. I_{Pri} is

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the average primary current. ω is the angular frequency of the grid voltage. If there is no loss, the energy stored in L_m is equal to the energy transferred to the grid. Assuming $|v_g| \approx v_o$, from (2) – (4), D_{DCM} can be derived as

$$D_{DCM}(t) = \frac{2}{V_{PV}} \sqrt{P_o L_m f_s} |\sin \omega t|$$

Where $D_{DCM, pk}$ is the peak value of D_{DCM} . In CCM, L_m is applied to V_{PV} during the turn-on time of $S1$, while the voltage across L_m is reflected the output voltage during the turn-off time. Using the voltage-seconds law for L_m , the duty ratio D_{CCM} in CCM is calculated as

$$D_{CCM}(t) = \frac{V_g |\sin \omega t|}{nV_{PV} + V_g |\sin \omega t|}$$

The duties D_{DCM} and D_{CCM} determine the relationship between the input voltage V_{PV} and output voltage V_o . The flyback operates in the DCM region when D_{DCM} is smaller than D_{CCM} . Fig 4. shows the operation regions of the flyback inverter in a half-cycle of the grid. As shown in Fig. 4, the flyback inverter operates in DCM at the low instantaneous power level or low solar irradiation level, although it operates in the CCM region above a certain power level in the ac line period. Because the flyback inverter has both operation modes over the whole ac line period, it performs as the flyback inverter with the hybrid mode. The boundary between the DCM and CCM regions varies according to the magnetizing inductance L_m . A lower L_m results in a larger DCM region at the given output power. The according to the magnetizing inductance L_m . A lower L_m results in a larger DCM region at the given output power.

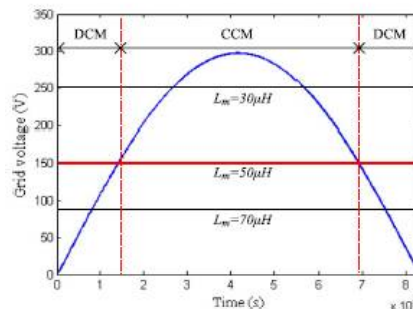


Fig. 4. The operation regions of flyback micro-inverter with grid voltage

III. CONTROL PLAN OF FLYBACK INVERTER WITH CONTROLLERS

A. PI controller

- A PI controller system is a kind of linear feedback control system. Smaller steady-state error, i.e., better reference following
- Faster dynamics, i.e., broader signal frequency band of the closed loop system and larger sensitivity concerning measuring noise
- Smaller amplitude and phase margin

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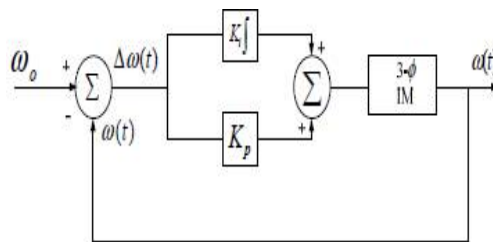


Fig. 5. PI controller

B. PR Controller

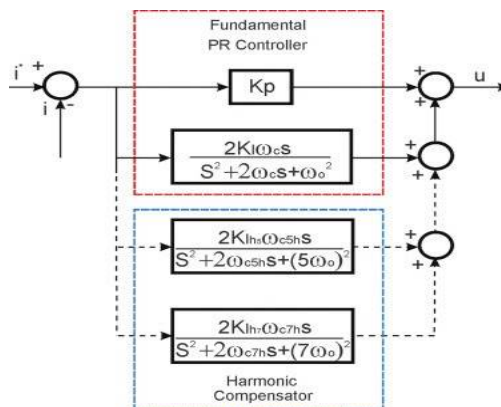
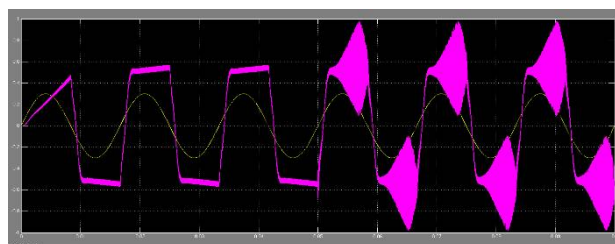


Fig. 6. PR controller

This is an overview of grid-connected renewable system is present. In the suggested control plan two current-control strategies is present. Firstly, the d-q control in the rotating synchronous reference frame using proportional integral regulators. Secondly the proportional resonant controller in the stationary reference frame. To obtain a high efficiency of the system, a harmonic compensator structure is used along with PR controller. A phase-lock loop is for synchronization algorithm.

IV.SIMULATION AND EXPERIMENTAL RESULTS



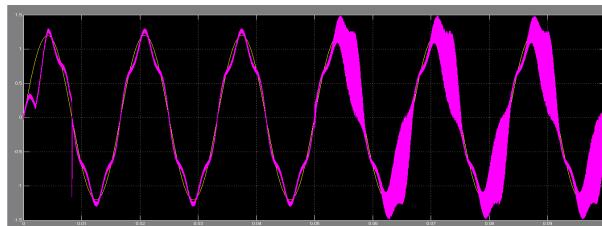
(a)

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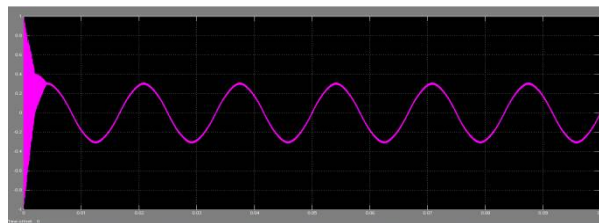
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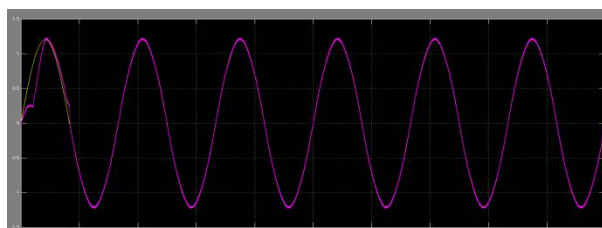
(b)

Fig. 7. Simulation results for the grid current I_g and I_{gref} with conventional control plan (a) Quarter load condition. (b) Full load condition

Above Fig. 7. Is the simulation results for the grid current I_g and I_{gref} with the conventional control plan for the quarter load condition and for the full load condition. According to the simulation results it's clearly reveals that disturbances are high by using the conventional control plan, and also the harmonic distortion is high in the conventional control plan.



(a)



(b)

Fig. 8. Simulation results of grid current I_g, I_{gref} with suggested control plan (a) Quarter load condition. (b) Full load condition

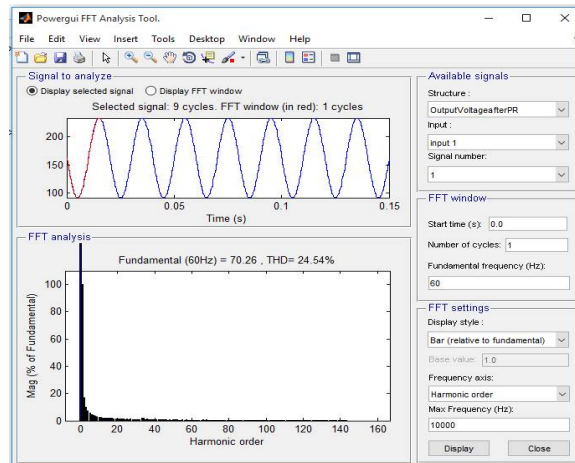
Above Fig. 8. Is the simulation results for the grid current I_g, I_{gref} with suggested control plan for the quarter load condition and for the full load condition. According to the simulation results it's clearly reveals that disturbance rejection performance are high in the suggested control plan, and the harmonic distortion is low compared with the conventional control plan.

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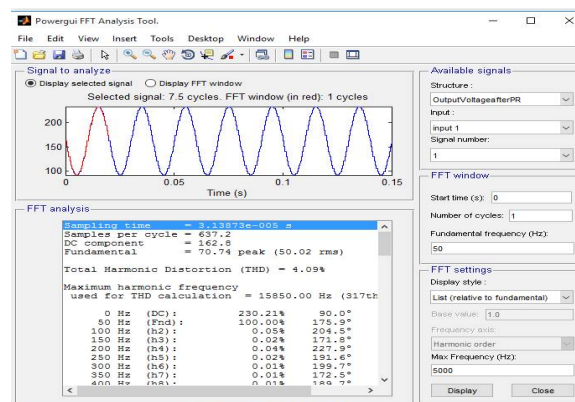
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(a)



(b)

Fig. 9. FFT analysis (a) PR controller (b)The combination of PI,2nd order filter

Table. 1

Type of controller	THD (%)
PI controller	26.78%
PR controller	24.54%
PI,2 ND order filter	04.09%

Fig. 7 shows the output current control performance when the conventional PI controller only with the duty ratio D_{CCM} is used. When the conventional control system is used, the grid current is distorted in the low power level. If the gain K_p increases to track the reference signal, the system becomes, in particular, the output current is not regulated by the poor tracking and rejecting disturbance performances in the power level only with the DCM region over the whole ac line period. On the other hand, in the suggested control plan, it is observed that the output current tracks the reference current and achieves almost zero tracking error without high proportional gain as shown in Fig. 8. But by using the PI

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controller with 2nd order filter will give total harmonic distortion to the smaller value as shown in table 1. As shown in Fig 9 the total harmonic distortion varies from PR controller to the combination of PI controller and second order filter.

V. CONCLUSION

The current control plan of the flyback micro-inverter with controllers for PV AC module is verified by the simulation, analysis, and experimental results. In the suggested control plan, the PR controller with HC provides the high system gain at fundamental and harmonic frequencies in both operation modes without using high proportional gain. The characteristic alleviates the trade-off between the control performance in DCM and stability in CCM when the conventional PI controller is used. Also, the proposed hybrid nominal duty ratio yielded from the proposed operation mode selection eliminates the disturbance more effectively and reduces the burden of the feedback controller. Flyback inverter with PI and second order filter gives total harmonic distortion to smaller value compared with the suggested control plan. From the simulation and experiment results, it is verified that the suggested control plan shows faster reference tracking and better disturbance rejection than those of the conventional plan. The suggested control plan encourages the many advantages of the flyback inverter with hybrid mode and makes it be used in the industrial field. The PI controller with the second order filter gives harmonic distortion to the smaller value.

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