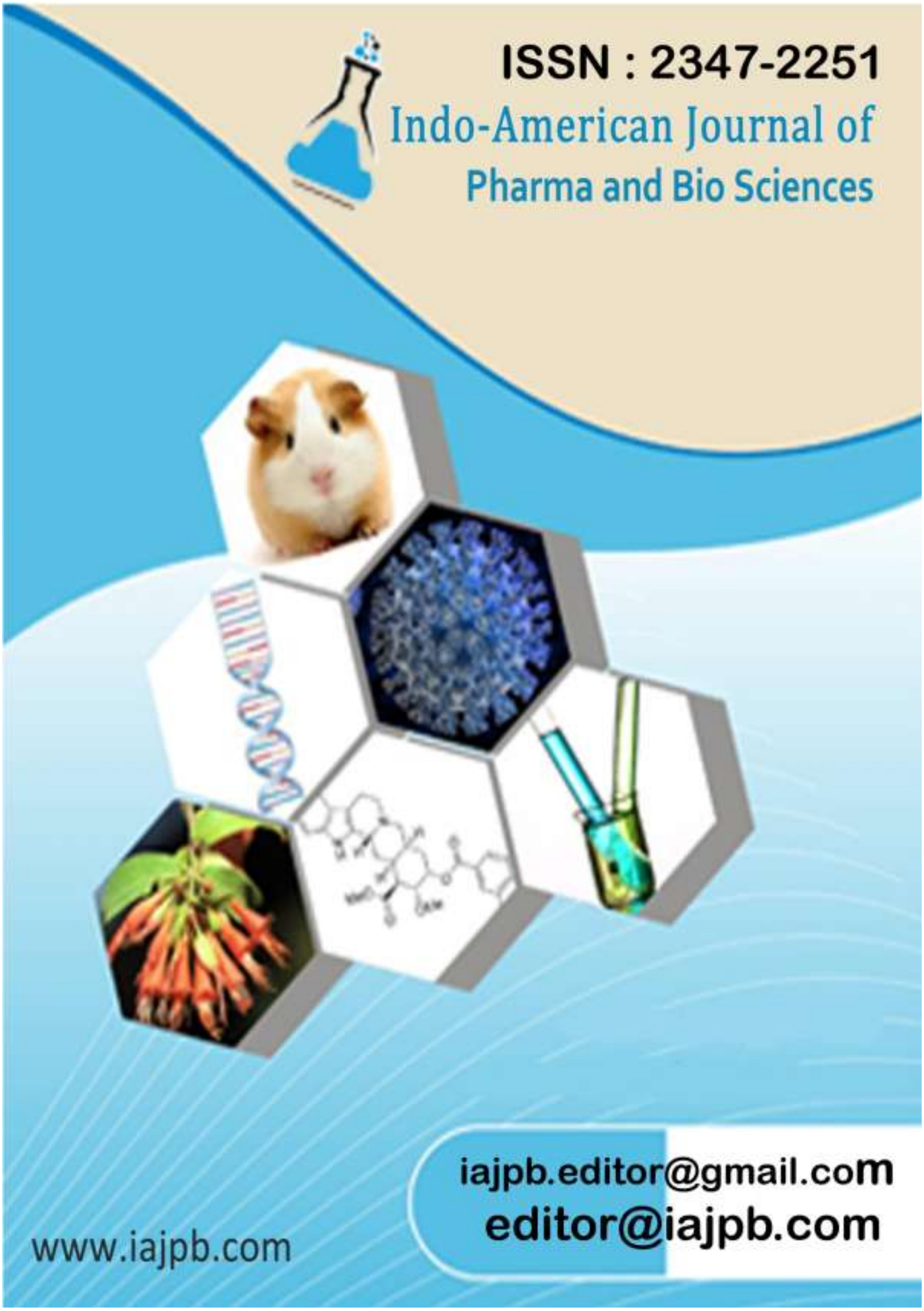


ISSN : 2347-2251

Indo-American Journal of Pharma and Bio Sciences

iajpb.editor@gmail.com
editor@iajpb.com

www.iajpb.com

Indo-Am. J. Pharm & Bio. Sc. 2022 *ISSN 2347-2251 www.iajpb.com*

Indo-American Journal of Pharma and Bio Sciences

Vol. 10 Issue 2 2022

Adaptive Fuzzy Proportional Resonant Controller For Photovoltaic Fly back Micro inverter With Hybrid Mode

c.Ganesh1, s.Sarada2, V.Venkata Srinivasa Rao3 Department of EEE, AITS Rajampet, ganesh.challa@gmail.com Department of EEE, AITS Rajampet, saradasasi@gmail.com Department of EEE, AITS Rajampet, vsrao281@gmail.com

Abstract; Rai, M. and Pradip's research (2000). Customers in the Fragrance Industry Value Perfume Brands. One of the world's leading academic journals on information technology, management and engineering.

p.177-192, Upper Saddle River, NJ: Pearson Prentice Hall for North-Western University. As a result of this (2008).

Including Yousaf and others, all of us males (2012). Studying brand loyalty in the cosmetics business, Journal of Economics and Sustainable Development/82160154, Vol. 8, No. 4, p327.

The work of others, including Anjali Sharma (2013). When it comes to purchasing beauty care products, female consumers in the Delhi region are more likely to stick with their favourite brands if they feel like they're getting good value for their money.

Index Terms— Photovoltaics (PVs), a single-stage inverter, and a current control method.

I.INTRODUCTION

The renewable-energy sources, the photovoltaic (PV) energy have been widely utilized in various industrial fields. The PV power systems can be classified into centralized, string, and ac module systems [1]. The ac module system, a low-power grid connected inverter called as the micro-inverter is mounted on a single PV module; it can track the individual maximum power point, and so, it reduces power losses by PV module mismatch and partial shading [2]–[4]. Moreover, the ac module system has higher reliability and easier maintenance than those of the other PV systems [5]. Thus, with these advantages, the ac module PV system has been recently considered as a trend of the future PV power systems. The worth of the micro-inverter is evaluated by its power conversion efficiency, shape of the output current, power density, reliability, and cost [6]–[8]. To meet these requirements, a single-stage flyback inverter topology has been adopted due to its simple circuit structure and potential for high efficiency and reliability. Moreover, the flyback inverter topology has both step- down and step-up functions; this characteristic is suitable for the PV applications where the inverter should operate in a wide voltage range. When the flyback inverter operates under the constant switching frequency, the operation modes can be classified as the discontinuous current mode (DCM) [9]–[14] and continuous current mode (CCM) [15]–[17]. The PV inverter called as the CCM flyback inverter has both operation modes; it inevitably operates in DCM at the low instantaneous power level or low solar irradiation level, although it operates in CCM at all instantaneous power levels for rated average power. Then, it can be regarded that the flyback inverter has a hybrid operation mode over the whole ac line period. Compared to a flyback inverter only with DCM, the flyback inverter with hybrid mode has numerous merits such as higher efficiency with lower current stress, higher power capability, and easier filter design. However, the control input-to-output current transfer function of the flyback inverter in the CCM region has a right-half plane (RHP) zero which results in the limitations of increasing the system gain and controller bandwidth. Since the operating point varies widely in the PV inverter applications, in particular, the controller should cover the minimum RHP zero. When a conventional proportional-integral (PI) controller is applied to the flyback inverter with hybrid mode, the proportional gain is designed to be relatively low for ensuring stability in all operating points [17]. The system gain of the flyback inverter in the DCM region is inherently much low. To achieve fast reference tracking and disturbance rejection performances, the high-gain feedback controller is required in the DCM operation. However, when the conventional PI controller is applied, the control gain is limited by the RHP zero in CCM. As a result, it causes unacceptable power quality and high total harmonic distortion (THD) by the poor control performance in DCM [15]. This is the reason why the use of the flyback inverter with hybrid mode is limited

The renewable-energy sources, the photovoltaic (PV) energy have been widely applied in numerous industrial domains. The PV power systems may be categorised into centralised, string, and ac module systems [1]. The ac module system, a low-power grid linked inverter dubbed as the micro-inverter is put on a single PV module; it can watch the individual maximum power point, and thus, it lowers power losses by PV module mismatch and partial shade [2]–[4]. Moreover, the ac module system has greater dependability and easier maintenance than those of the other PV systems [5]. Thus, given these benefits, the ac module PV system has been lately evaluated as a trend of the future PV power systems. The value of the micro-inverter is judged by its power conversion efficiency, shape of the output current, power density, reliability, and cost [6]–[8]. To achieve these needs, a single-stage flyback inverter topology has been used due to its simple circuit layout and potential for high efficiency and reliability. Moreover, the flyback inverter architecture provides both step- down and step-up functions; this characteristic is suited for the PV applications where the inverter should work in a wide voltage range. When the flyback inverter runs under the constant switching frequency, the operating modes may be characterised as the discontinuous current mode (DCM) [9]–[14] and continuous current mode (CCM) [15]–[17]. The PV inverter dubbed as the CCM flyback inverter has both operating modes; it unavoidably functions in DCM at the low instantaneous power level or low solar irradiation level, however it operates in CCM at all instantaneous power levels for rated average power. Then, it may be regarded as the flyback inverter has a hybrid operation mode over the complete ac line duration. Compared to a flyback inverter simply with DCM, the flyback inverter with hybrid mode has various benefits such as improved efficiency with reduced current stress, higher power capability, and easier filter design. However, the control input-to-output current transfer function of the flyback inverter in the CCM area has a right-half plane (RHP) zero which results in the restrictions of raising the system gain and controller bandwidth. Since the operating point varies greatly in the PV inverter applications, in particular, the controller should cover the minimum RHP zero. When a typical proportional-integral (PI) controller is applied to the flyback inverter with hybrid mode, the proportional gain is intended to be relatively low for guaranteeing stability at all operating points [17]. The system gain of the flyback inverter in the DCM area is naturally considerably low. To accomplish quick reference tracking and disturbance rejection capabilities, the high-gain feedback controller is necessary in the DCM operation. However, when the typical PI controller is applied, the control gain is restricted by the RHP zero in CCM. As a result, it creates inadequate power quality and significant total harmonic distortion (THD) by the poor control performance in DCM [15]. This is the reason why the usage of the flyback inverter with hybrid mode is limited

despite its numerous advantages. To circumvent the aforementioned difficulty, several prior research in [15] and [16] control the primary current instead of managing the output current since there is no RHP zero in the transfer function for the control input to the primary current. The control technique overcomes the challenges given by the RHP zero. However, the power quality is bad since this strategy regulates the output current indirectly. The proportional-resonant (PR) controller is an alternative of the PI controller. It delivers an infinite gain at a specified resonant frequency without utilising large proportional gain [18]–[20]. Moreover, because the controller provides flexibility of setting the resonant frequency, adding numerous PR controllers such as the harmonic compensator (HC) is feasible for correcting the harmonics of the specified fundamental frequency. In this study, the current control approach of the flyback micro-inverter with hybrid mode is suggested. The suggested control approach comprises of two components: the PR controller HC with fuzzy logic controller and the hybrid nominal duty ratio.

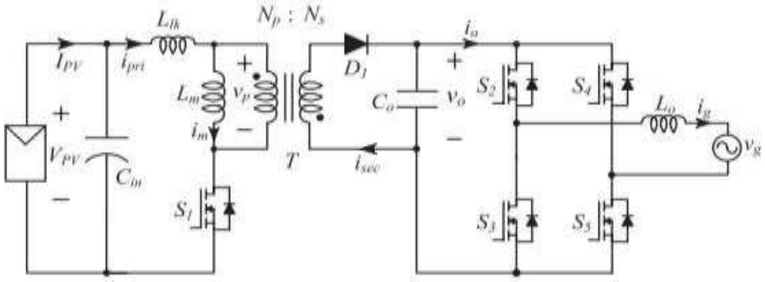


Fig. 1. Circuit diagram of the flyback micro-inverter.

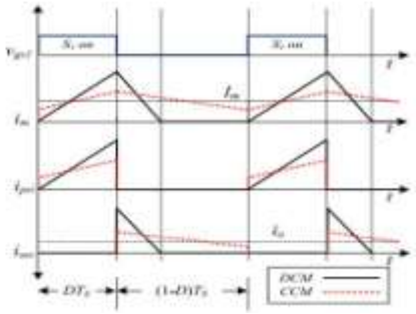
High gain at grid fundamental and harmonic frequencies and zero tracking error are both achieved by the PR controller with HC and fuzzy logic controller. The suggested operation mode selection affects the hybrid nominal duty ratio, which acts as a feed-forward control input. When the hybrid nominal duty ratio is used in the right operation zone, it can improve disturbance rejection and accelerate dynamics. Because of this, the flyback inverter with hybrid mode and the control approach we've developed have improved tracking and disturbance rejection in both modes of operation. Section II introduces the flyback inverter's fundamental functionality for each mode. PI controller difficulties are addressed in Section III, which shows the system's dynamic characteristics for each mode of operation. Then, the theoretical analysis of the suggested control technique is provided, and its superiority and validity are shown. In Section IV, the findings of both simulations and experiments are presented.

POLITICS OF FLYBACK INVERTER HYBRID OPERATION II

There is a flyback micro-inverter with a turn ratio of n(Ns/Np) and a full-bridge-type unfolding circuit (S2 – S5), as well as an output filter, shown in Fig. 1. The flyback converter uses a high switching frequency to convert PV electricity into a rectified sinusoidal waveform.. Switches S2 and S5 are turned on during the positive half-cycle of grid voltage vg, while switches S3 and S4 are switched on during the negative half-cycle of grid voltage vg in the unfolding circuit.

DCM and CCM Operations in a Stable State

The DCM and CCM modes of operation are categorised by the constant switching frequency fs. Every time a switch is made within a given time period, the magnetic field of an electrically insulating transformer is entirely de-magnetized, as shown in Figure 2. When S1 is activated, the dominant current is



Waveforms that are important in both DCM and CCM are depicted in the following figure.

VP7 D = I (t)

$(t)T$

(1)

Pri,$PK-DCM$

Lm

$DCM\ S$

The duty ratio in DCM is Ddcm. Lm's stored energy is stated as Elm.

The elm tree is a kind of evergreen

1Two packs of LmIPri

2(t) = 2LM (VP7DDCM(T)TS)2

(2)

Power balancing equations may be derived as long as the inverter is operating at full capacity.

$VgIg$

In other words, V I = P

(3)

Electricity generated by solar panels

the following formula may be used to calculate VPV IPri: (4)

where Vpv and Ipv represent the average voltage and current of a PV module, respectively. There are two kinds of Vg and Ig: Vg is the grid voltage, and Ig is the grid current. The average output power (Po) is referred to here. The typical primary current is denoted by Ipri. is the grid voltage's angular frequency. There is no loss of energy if Lm's stored energy equals the amount of energy that is sent to the grid. DDCM may be obtained from (2)–(4) by assuming that |vg| vo. 2

It is equal to P0LMFS|sin t| DDCM(T)

PV

(sin t)=dDCM,PK (5)

The peak value of Ddcm,pk is Ddcm,pk The voltage across Lm is reflected to the output voltage in CCM when S1 is turned on and Lm is applied to VPV at that period. The duty ratio Dccm in CCM may be determined by applying the voltage-seconds law to Lm.

$DDCM=$ Vg|t|sin(t)

The sum of nVP7+Vg|sint|

(6) The responsibilities. These two equations tell us how the input voltage (Vpv) and output voltage (vo) are related. The peak value of the primary current in DCM is represented in terms of amperes (1). Because of this, as illustrated in Figure 2, the main current's peak value is equal to the average magnetising current's peak value multiplied by CCM. Because the main current and the magnetising current are the same,

When S1 is activated, the duty ratio Dccm and the average value of the primary current Ipri may be used to express its average value as follows:

Im

For example, (t) = Ipri(t)

$DCCM(t)$

(7)

As a result of the power relationship in (2) and Fig.2, the maximum primary current Ipri,pk-CCM is computed as

Vpv

PV g

$2lmfs$

When it comes to PV, it's important to remember that

Each mode's peak ipri current is split by the turn ratio, and the secondary current is the same.

Hybrid Mode Flyback Micro inverter A

Time is separated into falling time Tf and a zero time t under DCM operation. It is possible to calculate Tf by using the formula in [6].

If t = nVP7dDCM,PK T, then

In other words,

(9)

$f\ vg\ S$

M.C.M. PK

where Vpv/Vg is represented as a ". Condition (10) is met in DCM because im is zero before the end of every switching period Ts.

= dDCM,PK (|sin| + k) for ton(t)

TS - TS - TS - (10)

Ddcm grows with output power, and the total of the turn-on and fall times is Ts. ' As a result of (5) and (10), the following is the critical duty ratio Dcri:

DCM,PKTS|sin t| ton(t) dDCM

$Ipri$,$pk-ccm$

$Ipri(t)$

In other words, (t) =

DCCM (t)

In a nutshell, VpvDCCM

+$2Lm$equal to i0 (kV)

The formula is as follows: + |v

$|vg(t)|$

(8)

D (t) : =

cri

Ts

Ts dDCM,PK(|sin t| + k) TS

In other words,

the sum of nVP7+Vg|sint|

(11)

Ddcm and Dccm are equal under boundary conditions, and the flyback operates in the DCM area if Ddcm is less than Dccm. According to Table I, Fig. 3 displays the flyback inverter's operating ranges in a half-cycle grid operation. Flyback inverters work in DCM at low levels of instantaneous power or of solar irradiation, as illustrated in Figure 3, but they function in CCM over a specific amount of power in the ac line period as well. Hybrid mode is achieved because the flyback inverter has both modes of operation available for the whole ac line duration. According to the magnetising inductance Lm, the border between the DCM and CCM zones can be shifted from one to the other. At the same output power, a smaller Lm results in a bigger DCM zone.

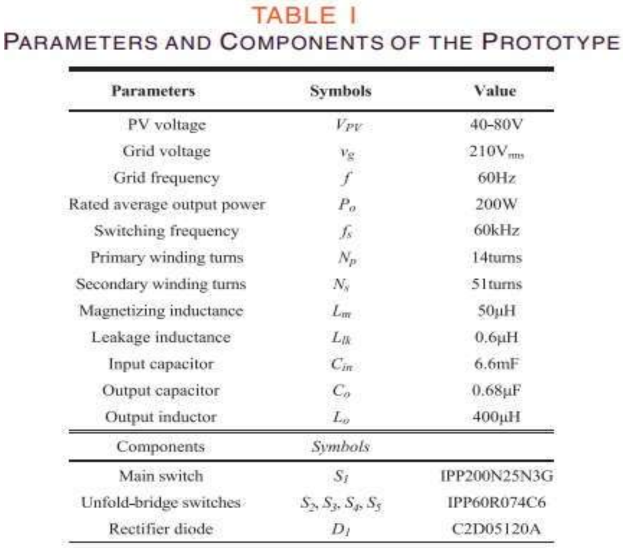


TABLE I

PARAMETERS AND COMPONENTS OF THE PROTOTYPE

Parameters	Symbols	Value
PV voltage	V_{PV}	40-80V
Grid voltage	v_g	210V$_{rms}$
Grid frequency	f	60Hz
Rated average output power	P_o	200W
Switching frequency	f_s	60kHz
Primary winding turns	N_p	14turns
Secondary winding turns	N_s	51turns
Magnetizing inductance	L_m	50μH
Leakage inductance	L_{lk}	0.6μH
Input capacitor	C_{in}	6.6mF
Output capacitor	C_o	0.68μF
Output inductor	L_o	400μH
Components	*Symbols*	
Main switch	S_1	IPP200N25N3G
Unfold-bridge switches	S_2, S_3, S_4, S_5	IPP60R074C6
Rectifier diode	D_1	C2D05120A

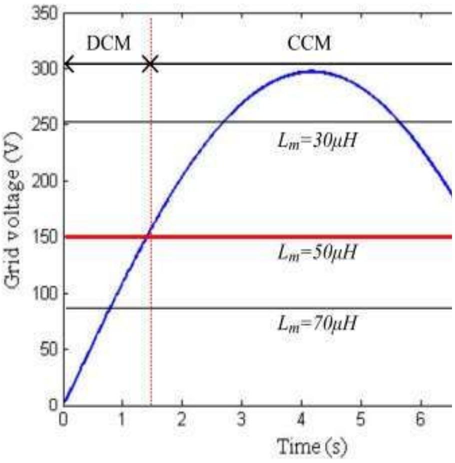


Fig. 3. Operation regions of the flyback inverter during a half-cycle of the grid voltage.

From (5) and (6), the critical magnetising inductance Lm,cri is as follows:

In other words, Lm,cri =1

$4p0fs$

2

The (VP7Vg)

$nVP7+Vg$

(12)

Lm must be lower than Lm,cri at a certain output power in order for the flyback inverter to function in the DCM area. The flyback inverter is solely affected by the high current stress in the DCM area, which results in large power losses and limits the power capacity of the device. The CCM zone expands and the maximum current stress reduces with time as Lm rises. The higher the Lm, the more efficient and powerful the device is. There is, however, a trade-off when determining the value of Lm; a greater Lm yields lower current stress but a bigger transformer size. In other words, while designing the flyback inverter with hybrid mode, Lm should be higher than Lm,cri and take into account permissible current stress and transformer size.

For control strategy of the flyback microinverter with hybrid mode, an investigation has been carried out

Issues with Control Flyback micro-inverters in hybrid mode should include a controller that can follow the reference and reject disturbances in both operating areas, according to this theory.

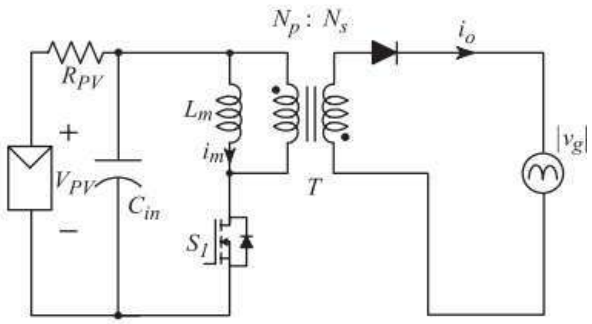


Fig. 4. Equivalent circuit of the grid-connected flyback microinverter.

Fig. 4 shows the equivalent circuit of the grid-connected flyback micro-inverter. Using the control input-to- output current transfer function introduced in [15], the transfer function Gid_DCM in DCM can be expressed as follows:

$G \qquad = VP7\ \sqrt{}\ p0$

(13)

i$d\ DCM$

Vg,rms

$2Lmfs$

where Vg,rms is the rms value of the grid voltage. Equation (13) is noted that the system gain in DCM is constant and very low at all frequency ranges. Using a small signal modeling, the transfer function Gid_CCM in CCM can be represented as

$AS + B$

ILM

where

$Gin\ CCM \ =$

Rin

Cim

Lm

$s2 + Lms + DCCM$

$-2RPV \quad k$

A=RPV

Cin

$(1 - DCCM)(Vc$ in+ $vg)\ n$

$B = 1 - DCCM\ (V \quad + vg - DI \quad R)$ (14)

$n \qquad$ in $\qquad n$

$CCM\ \ LM \quad PV$

CCM's control input-output current transfer function has a RHP zero from (14), which can be seen. Its minimal value occurs at the grid voltage peak when the output power is at its highest. The RHP zero changes with the operating points. When designing the controller for a flyback inverter hybrid, it is important to keep in mind the minimum RHP zero. The PI controller is employed in the traditional control system [17] to assure the tracking and rejection of disturbances. Table I contains a list of the parameters that were used. Instantaneous power under rated average power (DCM) is 25 W; peak voltage (Vg) under rated average power is zero RHP in CCM. A low proportional gain kp of the PI controller ensures that the operating point with the minimal RHP zero remains stable at all times. As a result, the traditional PI controller's gains are set at kp = 0.08 and ki = 64. As a result, the DCM region's flyback inverter can't keep track of the reference and reject grid voltage effects. At certain frequencies, a large proportional gain is necessary to boost the system gain. Although it boosts system gain at all frequencies, this might lead to the flyback inverter in the CCM area being unstable. Because of this, when applying for jobs. An entire control system is depicted in Fig. 4.3, which includes the PR controller with hybrid mode (HC) and the nominal duty ratio (Dn). It is the highest value of the reference grid current (or output current). Nominal duty ratio (Dn) is a feedforward control input that decreases the strain on the feedback controller by eliminating the disturbance effects. Only the duty ratio Dccm from equation (6) is used for the whole ac line time in equation [17] A voltage mismatch in the DCM area is caused by the Dccm duty ratio, which makes the feedback controller's job more difficult. This cost grows larger since the system gain in DCM is rather minimal. Flyback inverters operating in the DCM region should use the Ddcm duty ratio, which implies that the nominal duty ratio should be chosen based on the operation region in order to overcome the DCM mismatch. No extra current is required to categorise the various modes of operation.sensor, the critical duty ratio in (11) can be used; it is noted that the flyback inverter operates in the DCM region when the following condition is satisfied as

$$DDCM(t) \leq DCCM\ (t) \qquad (15)$$

Thus, the hybrid nominal duty ratio Dn in the proposed control strategy is determined as follows:

$D\ \ (t)$ = {$DDCM(t)$, if$DDCM(t) \leq DCCM$ (t)

(16)

n $DCCM(t)$, if $DDCM(t) \leq DCCM$ (t)

IV. Even more importantly, reducing disturbances in both modes of operation using a hybrid nominal duty ratio increases the performance of feedback controller.

V. SIMULATION AND EXPERIMENTAL RESULTS

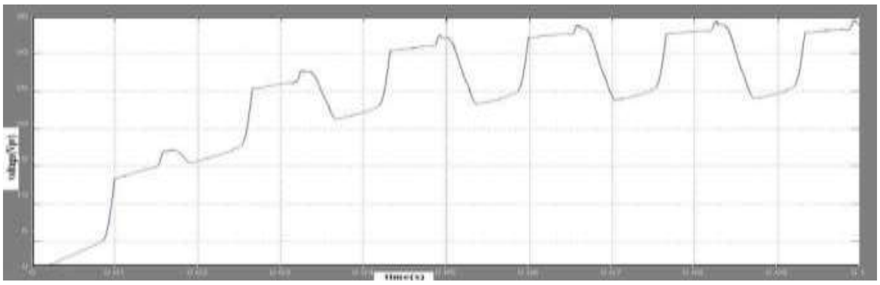
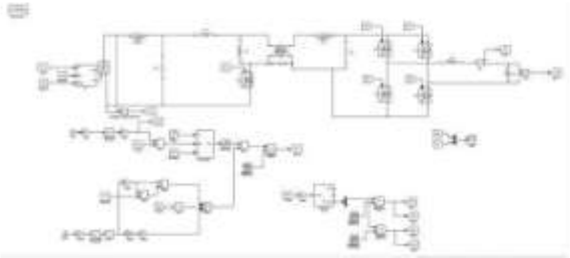


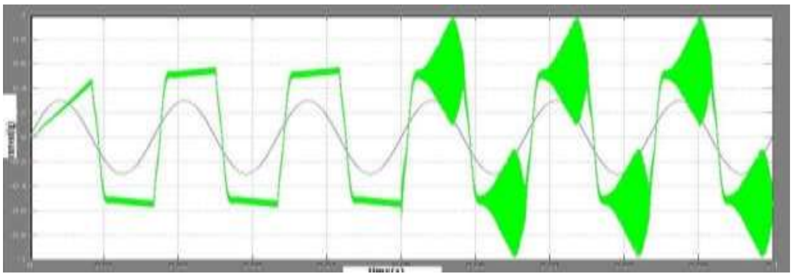
Figure 1 shows a flyback microinverter prototype and a simulator Psim that were used to test the suggested control strategy's feasibility and performance. It was decided that the nominal PV voltage and rated power would be 60 V and 200 W, respectively. Table I contains a list of all of the system's specific parameters and components. Analyzed data is used to develop controller settings. The simulation output for the photovoltaic module is given in the image below.

Figure 4 shows a simulation of the voltage Vpv input.



Microchip dsPIC33EP512GM604 was used with a 25-kHz sampling frequency to implement the prototype. When using the traditional PI controller with the duty ratio Dccm in (6), Fig. 4.1 demonstrates the simulation output current control performance Grid current is distorted at low power levels when the traditional control mechanism is applied.

Fig 4.1 SIMULATION CIRCUIT OF CONVENTIONAL INTERGRAL



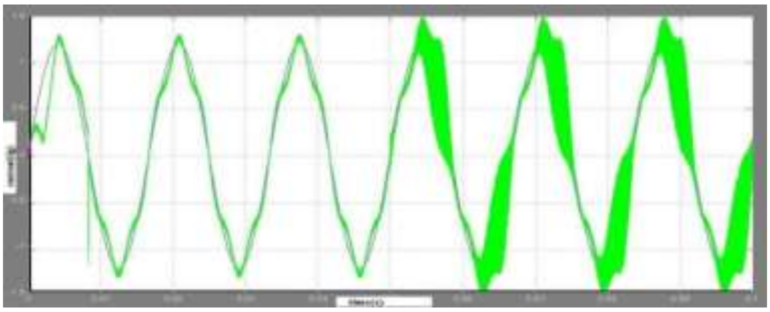


Fig 4.2 (a)

Fig 4.2 (b):

Fig.4.2:Simulation results for the grid current ig and its reference ig-ref when the conventional control system is applied.

(a) quarter-load condition.

(b) full-load condition.

The Total Harmonic distortion for the conventional control system by using PI controller is to be calculated for the both full load condition and quarter load condition.

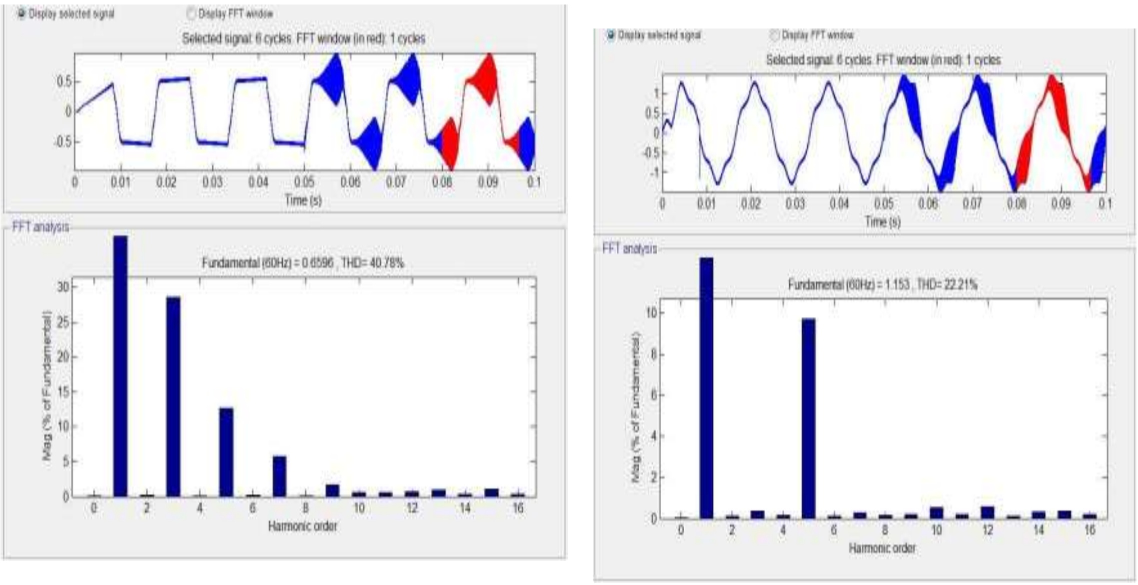


Fig.4.3: THD calculation for the conventional control system by using PI controller

(a) Quarter-load condition

(b) Full-load condition

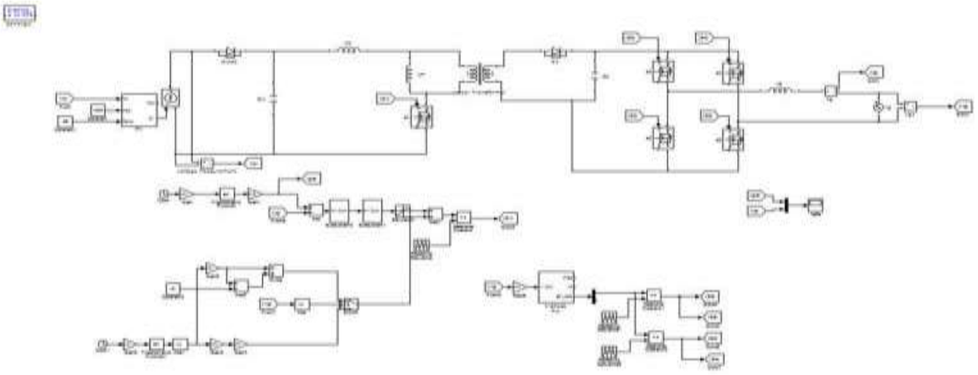
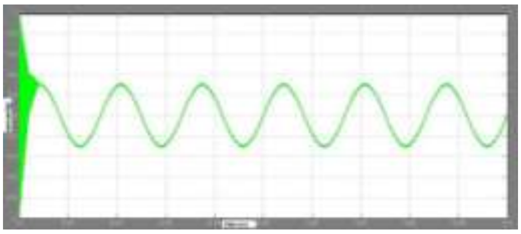
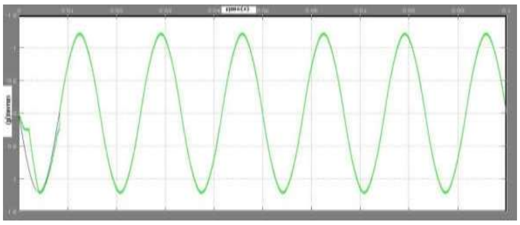


Fig.4.4: SIMULATION CIRCUIT OF PROPOTIONAL RESONANT CONTROLLER





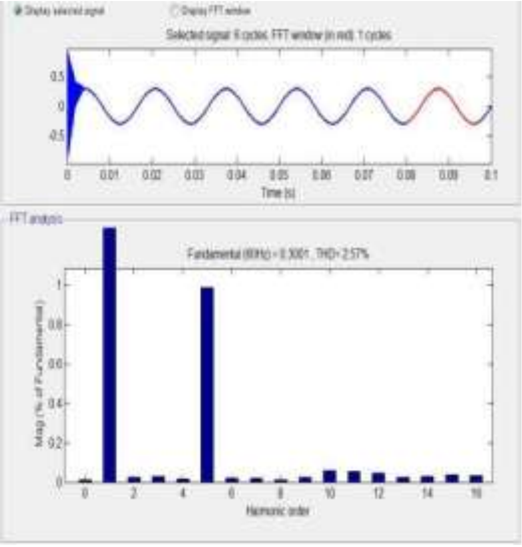
4.4(a)

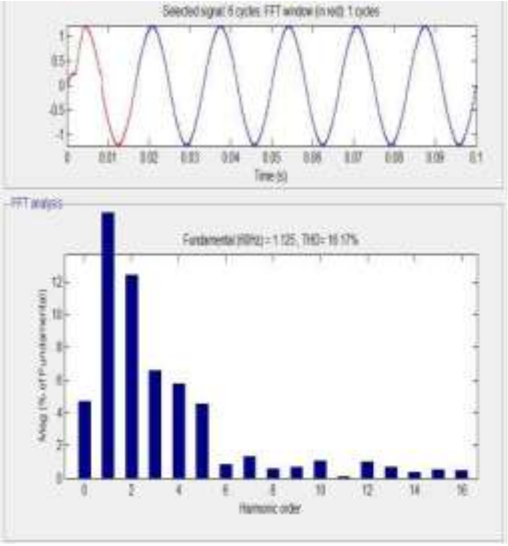
Fig.4.4: Simulation results for the grid current ig and its reference ig-ref when the PR system is applied

(a) quarter-load condition.

(b) Full-load condition.

Although the DCM area has poor tracking and rejection of disturbances, the output current is not restricted by this across the whole ac line duration. As demonstrated in Fig.4.1, the proposed control approach achieves practically zero tracking error without significant proportional gain. Fig.4.4 illustrates the experimental waveforms for grid voltage and current when the suggested control strategy is implemented. THD on the grid current is 16.17 percent at full load, and 2.57 percent at quarter load..





controller for the both

(a) Quarter-load condition

(b) Full-load condition

Fig. 4.6 shows the dynamic performance under the load variation. From Fig. 4.6, it is verified that the proposed control system makes the output current track well its desired value under the load transient state. Fig. 4.7 shows the current stress between the flyback inverter with hybrid mode and the flyback inverter operating only in the DCM region.

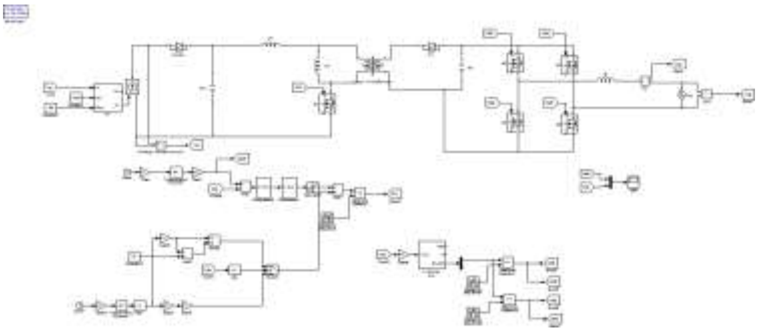
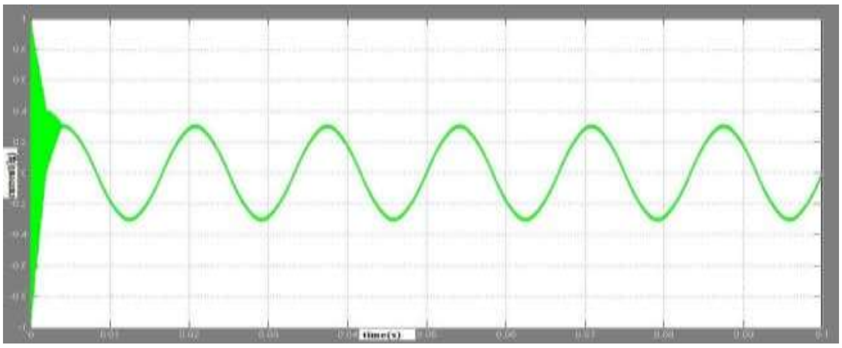


Fig.4.6: SIMULATION CIRCUIT FOR PROPOSED PR-CONTROLLER WITH FUZZY LOGIC CONTROLLER



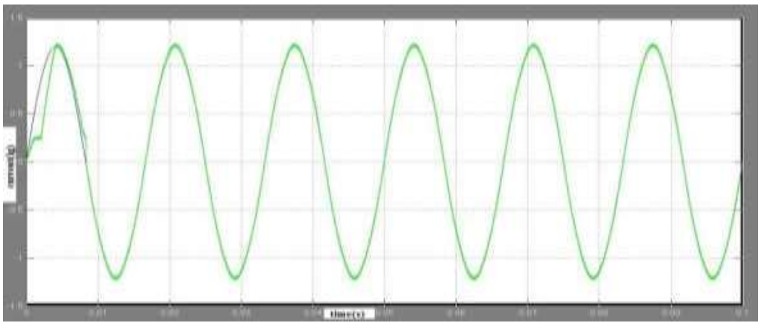


Fig.4.7: Simulation results for the grid current ig and its reference ig-ref when the PR controller with fuzzy logic controller is applied

(a) quarter-load condition.

(b) Full-load condition.

To ensure DCM operation for all operating points, the magnetizing inductance of the DCM flyback is set to 11 µH. From Fig. 4.7, it is observed that the flyback with hybrid mode has a much lower current stress in both primary and secondary sides than those of the DCM flyback inverter.

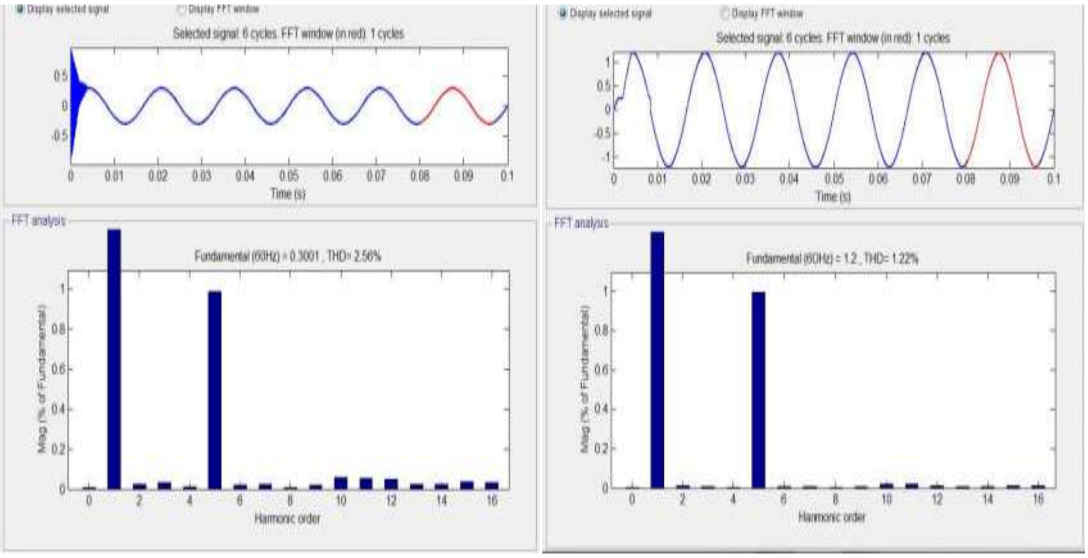


Fig.4.8: THD calculation for the PR controller with fuzzy logic controller from simulation results

(a) quarter-load condition.

(b) full load condition

The THD estimate for flyback inverters based on load circumstances is shown in the image above. The flyback inverter in hybrid mode has a decreased total harmonic distortion (THD) under all load circumstances, as is evident. The minimal THD for a quarter load is 2.56 percent, while the minimum THD for a full load is 1.22 percent....

VI. CONCLUSION

Analytical and experimental findings have confirmed the existing control technique of flyback micro-inverter with hybrid mode for the PV ac module. At fundamental and harmonic frequencies in both modes of operation, both modes of the proposed control strategy benefit from the PR controller with HC and fuzzy logic controller. When a standard PI controller is utilised, this feature reduces the trade-off between control performance in DCM and stability in CCM. With the suggested hybrid nominal duty ratio resulting from the proposed operating mode selection, the disruption is eliminated and the strain is reduced even further. Fuzzy logic decreases the harmonic output outcomes by employing the system. The proposed control approach, fuzzy controller, has been shown to be quicker in simulations and experiments.

In contrast to the typical technique, reference tracking and superior disturbance rejection. It is possible to employ the flyback inverter with hybrid mode and fuzzy logic system in the industrial area thanks to the proposed control method.

REFERENCES

[1] The following paper, "Weighted-efficiency enhancement control for a photovoltaic ac module interleaved flyback inverter employing a synchronous rectifier," was published in the December 2014 issue of IEEE Transactions on Power Electronics, and it can be found at Y.-H. Kim, J.-W. Jang et al.

[2] IEEE Transactions on Industrial Electronics, volume 59, no. 12, December 2012, pages 4713–4722. [2] Petrone, Spagnuolo, and Vitelli, "An analogue approach for distributed MPPT PV applications."

[3] [3] A module-integrated isolated solar microinverter by H.-J. Chiu and colleagues Vol. 60, Issue 2, Pages 781–788, February 2013.

[4] A single-stage flyback PV microinverter with soft switching was developed by N. Sukesh, M. Pahlevaninezhad, and P. K Jain and published in the IEEE Transactions on Industrial Electronics in 2014, volume 61, number 4, pages 1819–1833.

[5] An enhanced flyback inverter for solar ac module applications was developed by M. Gao, M. Chen, C. Zhang, and Z. Qian, and published in IEEE Transactions on Power Electronics in July 2014, volume 29, number 7, pages 3428–3444

[6] "A weighted efficiency-oriented design technique of flyback inverter for ac photovoltaic modules," IEEE Trans. Power. Electron., vol. 27, no. 7, pp. 3221–3233, Jul. 2012.

[7] inverter for ac photovoltaic modules that reduces low-frequency ripple current on the dc input, published in Proc. IEEE PESC, 2002, pp. 1483-1488, by T. Shimizu, K. Wada and N. Nakamura.

[8] There is a "very efficient microinverter" featuring a soft switching step-up converter and a single switch-modulation inverter that was developed by WJ Cha and colleagues (CY Cho, JM Kwon, and BHK) ([8]). Vol. 62, Issue 6, Pages 3516–3523, June 2015. IEEE TIA Trans. Ind. Electron.

[9] Z. Zhang, X.-F He, and Y.-F Liu, "An optimum control approach for PV grid-tied, interleaved flyback microinverters to achieve high efficiency across a wide load range," IEEE Trans.

[10] A novel control technique for boosting weighted efficiency in photovoltaic ac module-type interleaved flyback inverter, IEEE Trans. Power Electron, vol 28, no 6, June 2013, pages 2688–2699, by Y.-H Kim, Y.-H Ji, J.-G Kim, Y.-C Jung, and C-Y Won.

[11] the current-source flyback inverter for decentralised grid-connected solar systems, IEEE Transactions on Energy Conversion, vol. 23, no 1, March 2008, pp. 281–293.

[12] A single-stage microinverter without the use of electrolytic capacitors has been proposed by Hu, Harb, Kutkut, Shen, and Batarseh in IEEE Trans. Power Electron., Vol. 28, No. 6, June 2013. S. Zengin

[13] Decoupling capacitor selection in DCM flyback PV microinverters considering harmonic distortion," IEEE Trans. Power. Electron., vol. 28, no. 2, pp. 816–825. Feb 2013.

[14] Zero Voltage-Switched Interleaved Flyback Converter (ZVSIFC)," in Proc. 31st INTELEC, pp. 1–6, 2009.

[15] An inexpensive flyback CCM inverter for the ac module application has been proposed by Y. Li and R. Oruganti in IEEE Trans. Power Electron., 27(3), 1295–1303, March 2012.

[16] In the IEEE Transactions on Industrial Electronics (TIE), T V Thang, N M Thao, D H Kim, and J H Park present their "Analysis and design of grid-connected photovoltaic systems with multiple integrated converters and a pseudo-dc-link inverter," published in July 2014, pp 3377–3386, in which they discuss their research.

[17] An integrated flyback converter for PV power applications may be dynamically modelled and controlled using the IEEE Trans. Ind. Electron. 61(3), pp. 1377–1388, in March of 2014.

[18] LCL filter-based grid-connected inverter: A novel feedback approach for PR current management of LCL-filter-based grid-connected inverter," IEEE Trans Ind Electron, June 2010.

[19] For grid connect LCL fuel cell power inverter inverter, [19] Park SY, Chen CL, Lai J-S and Moon S-R, "Admittance correction in current loop control proportional resonant controllers," IEEE Trans Power Electron, vol 23, no 4, pp 1716–1723, July 2008

[20] Grid-connected voltage-source converters use proportional resonant controllers and filters (Teodorescu et al., 2006), published in Proceedings of the Institute of Electrical

Engineers—Electronic Power Appl., vol. 153, no 5, pp, 750–762.