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Power Flow Control in Distributed Generation System of PFC Rectifier for DC Motor Drive

Maloth Naresh[1] and Ramesh Kumar Tripathi[2]
[1,2] Department of Electrical Engineering MNNIT Allahabad
[1,2] ree0114@mnnit.ac.in1 and rktripathi@mnnit.ac.in

***Abstract**:* In this paper is to performance and analysis of grid connected power flow control and power quality improvement in distribution generation (DG) system a new topology of harmonic injection current, connected for a grid mode and DC motor drive. Inherently the system power factor is low and it has high harmonic content in the current. The Swiss rectifier is based on harmonic current injection methods on power flow control and implementation of Power factor correction (PFC), Rectifier, the harmonic mitigating pulse width modulation (PWM) technique have been used to reduce the harmonics for power quality improvement. The renewable sources have been used as DC source and control technique has been used with step up DC-DC converter to regulate DC-link voltage. The second close loop control has been done for voltage source inverter to stabilize its terminal voltage. The DC-AC converter provides the bidirectional power flow between point of common coupling (PCC) and local load. The step up converter regulates the DC link voltage to exchange the power with the three phase feeders, also it is conformed the harmonic current can be satisfied with the proposed method. The simulation Study is performed in MATLAB/ SIMULINK.

Keywords: DG, Islanding Modes, Total harmonic distortion (THD), PLL, PWM, Power Converter, Swiss Rectifier and Matlab Simulink.

1. Introduction

Nowadays the quantity of DG system, with renewable energy sources such as PV, power systems, is rising in the distribution system. The electrical energy is flows to the customers via transmission and distribution network, the reactive and real power flows in the transmission lines. The power flow can be reverse from the transmission and distribution line through a substation [1]-[3]. The voltage is appropriately without real power decrease of DG, a distributed PFC is introduced in [9]. Now a days the number of power quality problems like harmonics, PFC, frequency and voltage in electrical power system. The output voltage can be controlled using PWM control techniques. This PWM is used to mitigate current and voltage waveform variation and to get better power quality. The reliable energy is provide increasing demand & environmental quality, extra pervasive utilize a small-scale renewable energy sources; modernization of the electricity sector, power markets and active involvement of customers to grid operation. In a number of researches, converters comprise DC voltage controller for PFC to sustain the DC electrical energy contained by particular limits. Fig. 1 exposed the grid connected RES used to improve the power quality. Both converters are associated at PCC. The generated reactive power is can be used for voltage regulation and the DGs is control the voltage were installed in distribution system it can be used for reduce the reactive power of DG. The PFC is most important of DGs in future. The DG systems are needed to manage the DG power, to decrease the energy with observance the power factor (PF). If the reactive power is not sufficient to control the voltage, the DG system has to decrease the PF.

The 3 phase PFC rectifier is usually being used front end rectifier in elevated power supply. If the range of DC-link capacitor in a DC machine drives system harmonics is reduce, the input harmonic current are reduce, the standard protocol IEC 61000[20]. The benefit of the SR rectifier is high efficiency. The information of the most important occupation of a DC-AC converter & 3- phase passive bridge rectifier is enough to apply a 3-phase PFC rectifier input current is obtained by

$$i_{opt} = \frac{v_{mid}}{V_p} . I_p \tag{1}$$

Where i_{opt} optimal injection is current, V_p are three phase input phase voltage, v_{mid} magnitude voltage and I_p current. So both power converters with power flow control in distributed generation system of PFC rectifier for dc motor drives system, grid connected mode and islanded mode proposed in this paper exposed in fig. 1.

2. Power Flow Control (PFC)

The PFC is a steady state condition whose active and re active power streams under load conditions. The DG system is utilizes a VSC, its give inactive and reactive power is

$$P = \frac{V_S V_{cf}}{X} \sin\delta \tag{2}$$

Here V_S = main source voltage, X = line reactance, V_{cf} = main receiving Voltage and δ = Phase angle, If $V_A > V_{Asource}$ the DG is given to the reactive power, when $V_A < V_{Asource}$ DG absorb and direct manage to the grid [7].

$$V_A \cos\beta = V_{source} \tag{3}$$

$$\frac{V_A \sin\beta}{X_q} = I_{Asource} \tag{4}$$

The rms voltage (V_A),

$$\sin\beta = \frac{P_{source} X_L}{V_{Asource} \cdot V_A} \tag{5}$$

$$\beta = \sin^{-1}\left(\frac{P_{source} X_L}{V_{Asource} \cdot V_A}\right) \tag{6}$$

$$Q_r = \frac{V_s V_r}{X_L} \cos\theta - \frac{V_r^2}{X_L} \tag{7}$$

$$Q_{source} = \frac{V_A V_{Asource}}{X_q} \cos\beta - \frac{V_{Asource}^2}{X_q} \tag{8}$$

Where X_L is inductive reactance, X_q is synchronous reactance. The β angle, DG voltage amplitude of V_A is,

$$V_A = \left(\frac{V_{Asource}^2 - Q_{source} \cdot X_L}{V_{Asource} \cos\beta}\right) \tag{9}$$

3. Characteristics of hybrid active 3rd harmonics injection and DG system

A 3-phase high PF rectifier operation of the buck-type converter active injection current is low frequency at bidirectional switches, in Fig 1 showing the renewable energy and grid connected DC motor drive by utilizing DC-DC converter and PFC rectifier. The output voltages of inverter are controlled using PWM techniques, and have two components. The primary is quadrature axis through line current, and the impedance to be injected. The DC-link is used for regulate the DC voltage to replace the power with 3-phase feeders, and VSI is used for system stabilize to the voltage regulation on closed loop system. The bi-directional converter is control the power flow at PCC on local load. The LC filter is given the input voltage through PFC rectifier to regulate the power and its connected to dc motor drives.

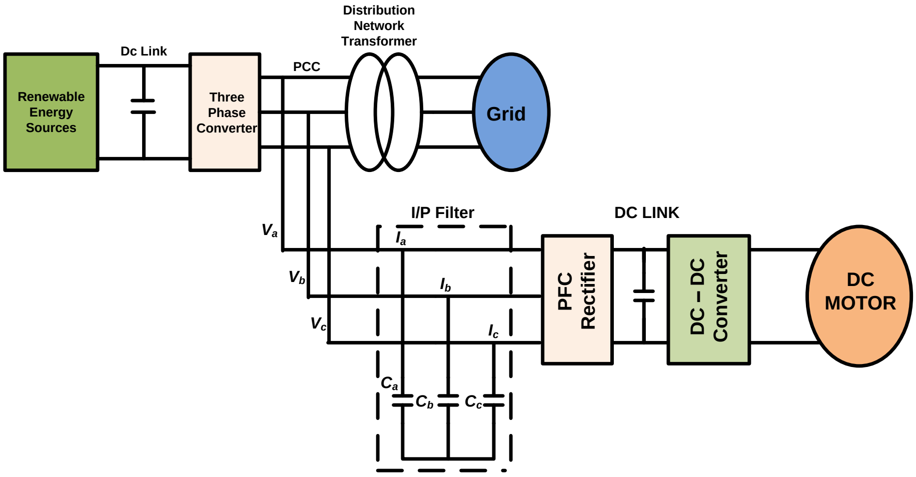


Fig. 1 Proposed Block Diagram

3.1. DC- DC converter

The Fig. 2 shows the PWM technique is used to control a number of DC-DC power converters which are coupled during the DC distraction lines together. The renewable energy sources is used to generate the DC power, in that case switch is on the inductor is charging the current and boost the converter through $H_{V\text{-DC}}$ dc voltage gains to reference voltage. The controlled dc voltage at reference signal is the PI controller and passes the current through boost converter and provides the PWM signals. The output voltage from the boost converter is used for compared the voltage fed forwarded. The current sensor is $H_{i\text{-boost}}$ is regenerating the current and gives the pulses through PWM. The DC-DC step up converter switches based on the semiconductor technology as well as the output filter

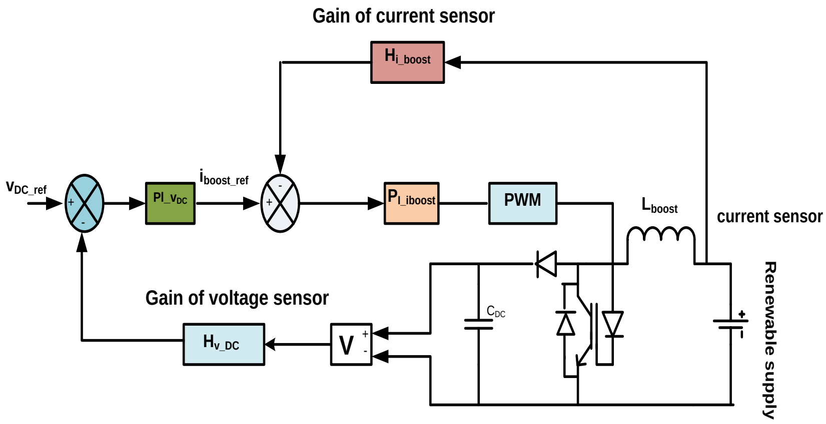


Fig. 2 DC voltage / current control

Open loop PI controller is,

$$PI(s) = k_p + \frac{k_i}{s} \tag{10}$$

$$PI(s) = \left(\frac{k_p s + k_i}{s}\right) = k_p \left(\frac{s + \frac{k_i}{k_p}}{s}\right) \tag{11}$$

Where $s = j\omega$

$$PI(j\omega) = k_p \left(\frac{j\omega + \frac{k_i}{k_p}}{j\omega}\right) \tag{12}$$

$$k_p \cdot \frac{G_{OL}}{\omega_{cf}} = 1 \tag{13}$$

Where, G_{OL} = open loop gain and W_{cf}= angular frequency

$$k_i = k_p \cdot \frac{G_{OL}}{\tan(mf)} \tag{14}$$

$$\text{(Or)}\ tan(mf) = \omega_{OL} * \frac{k_p}{k_i} \tag{15}$$

Where $mf = phase\ margin$

3.2. DC – AC Converter

In Fig.3 exposed the PI controller used reduces the error and to generate pulses to give the gate pulses to VSI. The switching frequency is to reduce the bandwidth voltage of low power factor and improve the power quality. The control correctly to continue the DC-link is used to stable voltage regulation. The reference voltage is forward to the resonant controller to control the voltage magnitude, generate the reference current on the DC-AC step up converter to using PI controller to reduce the obtainable error. The current sensor ($H_{i\text{-DC-AC}}$) and voltage sensor ($H_{V\ \text{–DC-AC}}$) gains are connected to parallel to control the existing error. The charged capacitor and inductor is connected to the load and grid. On the other hand, the outer loop is responsible to keep the constant DC-link voltage.

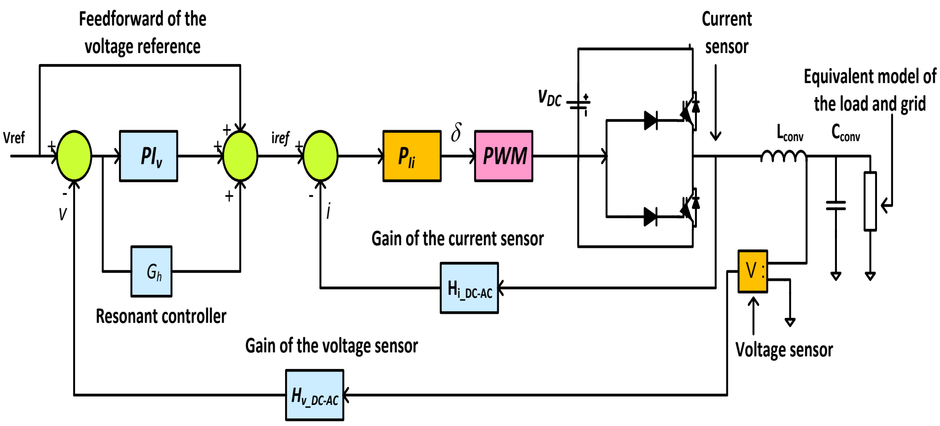


Fig. 3 AC voltage / current control

For ideal case,

$$G_{AC}(s) = \frac{Y(s)}{E(s)} = \frac{2k_i s}{\left(s^2 + \omega^2\right)} \tag{16}$$

For non ideal case,

$$G_{AC}(s)=\frac{Y(s)}{E(s)}=\frac{2k_i(\omega_c s+\omega_c{}^2)}{s^2+2\omega_c s+(\omega_c{}^2+\omega^2)} \tag{17}$$

ω_c Cut off frequency << W

$$G_{AC}(\mathrm{s})=\frac{2k_i\omega_c s}{\left(s^2+2\omega_c s+\omega^2\right)} \tag{18}$$

For resonance frequency and nth harmonic order

$$G_h=\frac{2k_{ih}+\omega_{ch}}{\left(s^2+2\omega_{ch}s+\left(h\omega_o\right)^2\right)} \tag{19}$$

3.3. Swiss rectifier (SR)

The Fig. 4 shows the three phase rectifier on six pulse bidirectional switch that buck type PFC rectifier. Main +Ve and -Ve switches iT+ and iT- can be perfumed two phase voltage diode bridge output voltage [13]. The power transmitter TH+ and TH- of distributed the 3-phase dc output current can be to such as after the LPF sinusoidal in mains phase. In SR rectifier is high efficiency and improve the power factor correction (PFC), low frequency diodes DF+ and DF- is LPF by the inductor [15]. The 3-phase (Va>Vb>Vc). a DC-DC buck converter is small striking is five switches in the current path to leading low losses.

$$V_0<1.244v_n,\ l-l,rms \tag{20}$$

Where V_0 = output voltage

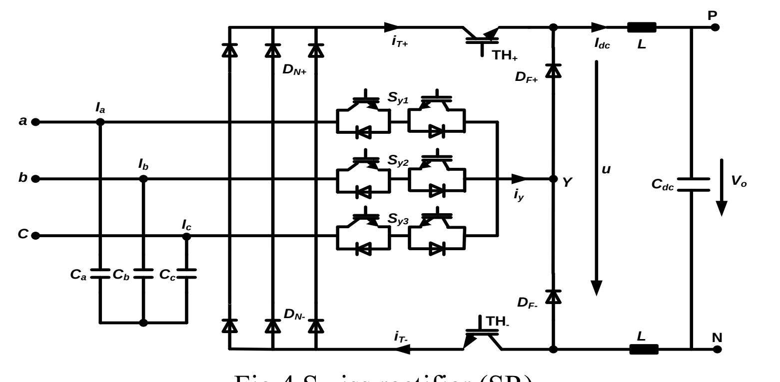


Fig.4 Swiss rectifier (SR)

Three phase voltage is

$$\left.\begin{aligned}V_s&=V_N*\sin(wt-2\pi/3)\\V_T&=V_N*\sin(wt-4\pi/3)\end{aligned}\right\} \tag{21}$$

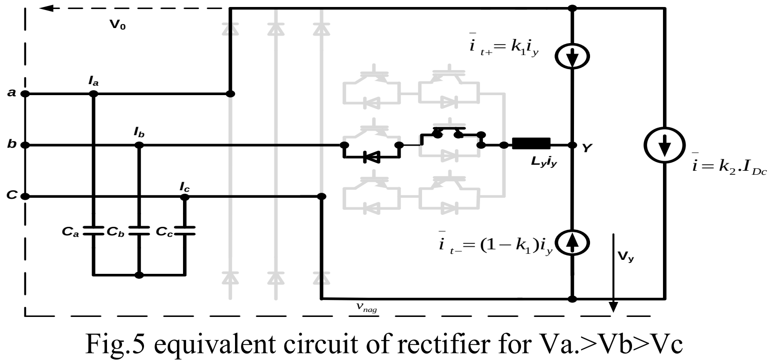


Fig.5 equivalent circuit of rectifier for Va.>Vb>Vc

Terminal Y is relative on time of power transmitter i_{T+} and i_{T-} as $(1-k_1)$,

$$v_y = k_1 v_a + (1-k_1)v_c = k_1 v + v_c \tag{22}$$

The duty cycle k_1 given by

$$v_{pos} = \max(v_a, v_b, v_c) \tag{23}$$

$$v_{neg} = \min(v_a, v_b, v_c) \tag{24}$$

$$k_1 = \frac{-(v_{pos} + 2v_{neg})}{v_{pos} - v_{neg}} = \frac{v_{bc}}{v_{ac}} \tag{25}$$

$$\bar{I} = k_2 I_{dc} \quad with\ k_2 = \frac{v_o}{v_{pos} - v_{neg}} \tag{26}$$

3.4. Switching Losses

The Fig 6 is exposed the switching frequency during every pulses to switching losses. When the switch is on the current commutate the phase from (101t0 110), the switch is off the losses will be occur. In second condition the switch is on the current flowing through freewheeling diode from (110 t0 101), the losses will be occur when switch off period. Third condition switch is on the current is commutate from (101t0 110), losses will be reduced when switch off. Switch is on after freewheeling condition & commutation of the current from the freewheeling diode from (010 to 110), where turn-on losses in the switch.

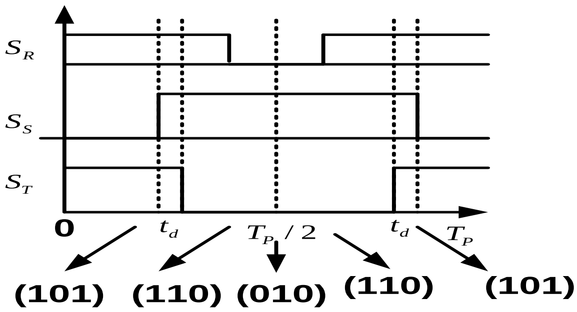


Fig.6 Switching Losses

3.5. Grid Characteristics

The main power line interrelated to the utility grid is 380V, 3-phase AC line. The DG system is 13.8 kV feeders is connected with 69 kV straight line at some point in 69/13.8 kV substation [8].

$$P_{sc} = P_{grid} = \frac{V^2_{AB\ source}}{X_L} \tag{27}$$

$$P_{sc} = \frac{V_{AB}{}^2}{\omega L_{grid}} = \frac{V_{AB}{}^2}{2\pi f L_{grid}} \tag{28}$$

Where X is a factor and $1 < X < 100$, PLL is analysis by

$$PI(s) = K_P + \frac{K_i}{s} \tag{29}$$

$$H_{cl}(s) = \frac{\left(K_P + \frac{K_i}{s}\right)\frac{1}{s}}{1+\left(K_P + \frac{K_i}{s}\right)\frac{1}{s}} \tag{30}$$

$$H_{cl}(s) = \frac{(K_P s + K_i)}{(s^2 + K_P s + K_i)} \tag{31}$$

PLL transfer function is

$$(s^2 + K_P s + K_i) = s^2 + 2\varepsilon\omega_n s + \omega_n^2 \tag{32}$$

Where, $2\varepsilon\omega_n = K_P$, $\omega_n^2 = K_i$

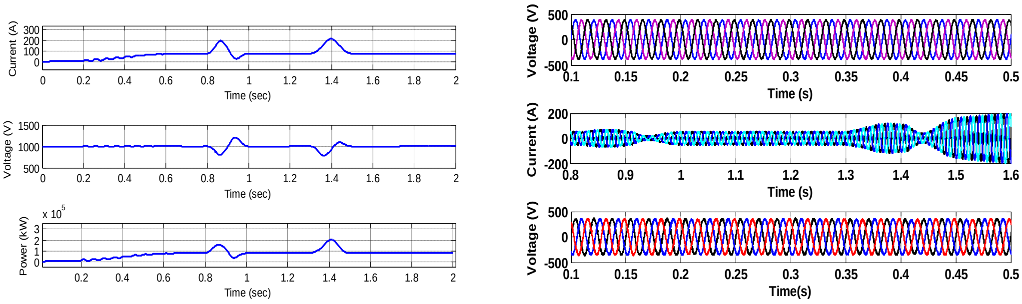
4. Simulation Result

Results are explained in three cases each case having a constant distribution generation system, operation of boost converter and active and reactive power generation system of islanded mode, when system is connected with grid mode and connected with dc motor drive system has been explained, and observed all the outputs, finally all outputs all examined inductively in different environmental conditions.

Table 1. Simulation Parameters.

Parameters	Values
Stator resistance (r_s)	0.2761
Rotor resistance(r_r)	0.1564
Stator inductance(L_s)	2.2mH
Rotor inductance(L_r)	2.2mH
Mutual inductance(M)	77.2mH
Voltage	380/440 V
Power	20 HP
DC Inductor	610 μH
Current injection inductor	2 μH
Switching frequency	36 kHz
Output capacitor	470 μF
Input Capacitor	4.4 μF
Rated voltage	380/440 V
Rated Frequency	50 Hz

4.1. Case-1 Performance test under DG with Non linear load from grid



(a) (b)

Fig. 7 (a) Operation of Boost Converter and (b) Active power from Grid

In fig 7(a) and 7(b) exposed the voltage and current at boost converter operation, that time the power exchange is 0.2 to 0.6 sec observed and active power from grid same as the current and voltage output waveforms. The load connected after 0.8 sec at 70kW & after 1.3 sec at 60kW. The observed the power transfers of unsettling disturbances and to improve PQ. The active and reactive power of the grid connected VSI is revise 2% and the load current THD is more than 115%, the islanding operation of power flow control (PFC) as exposed in fig 8 (a),(b),(c) and (d).

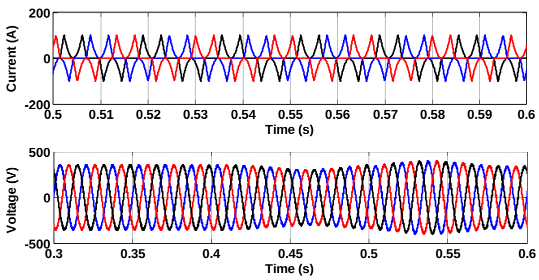


Fig. 8(a)

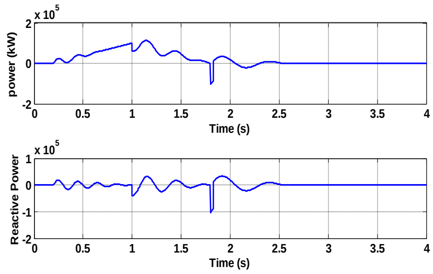


Fig. 8(b)

Fig. 8 DG with Non linear load current and voltage

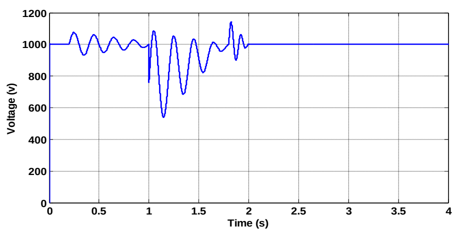


Fig 8 (c)

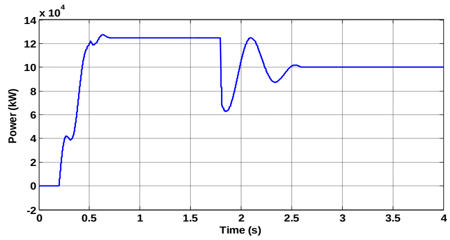
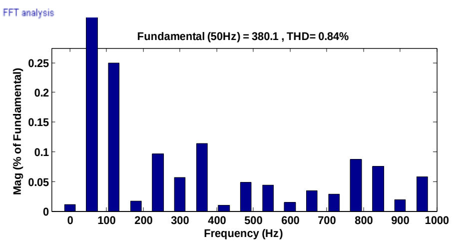
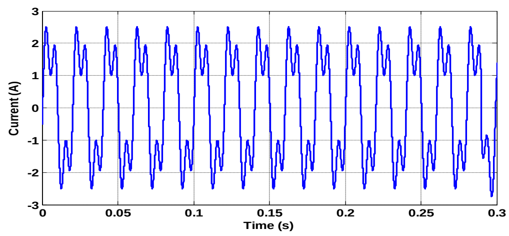


Fig. 8 (d)



(a)

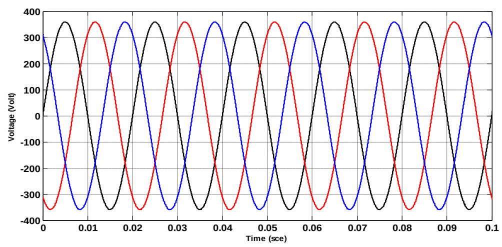


(b)

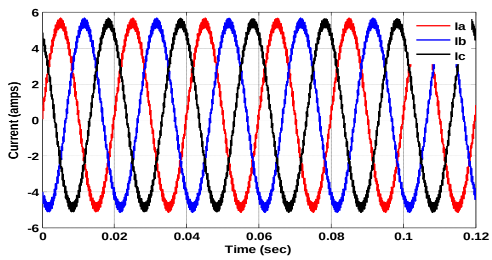
Fig. 9 (a) Frequency at non linear load and (b) lagging Current

The frequency at non linear load is 50 Hz 380.1, THD is 0.84 % exposed in Fig. 9. The load lagging current & lagging PFC as exposed fig. 9 (b)

Case-2 Performance test under Grid Connected Mode



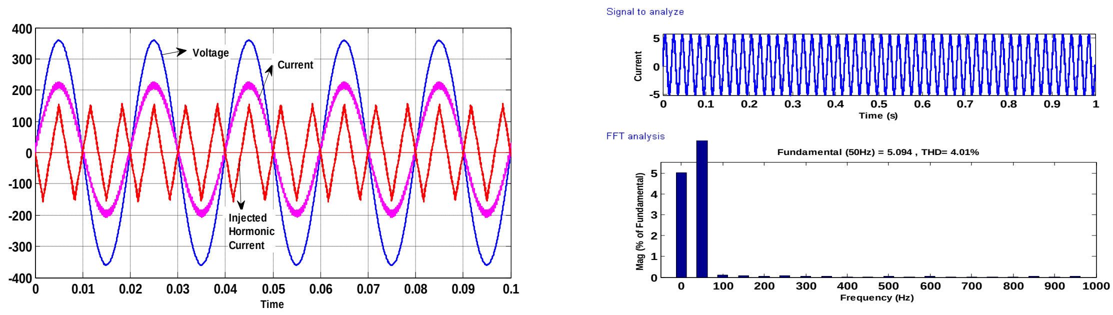
(a)



(b)

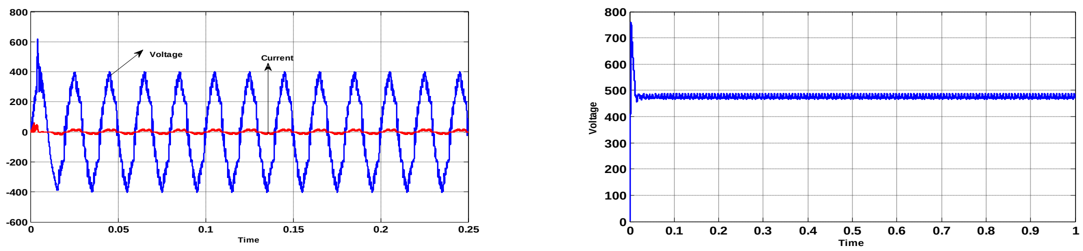
Fig. 10 under grid connected (a) 3- Phase Voltage and (b) 3- Phase Current

The case 2 grid connected mode of the PFC at, Fig.10 (a) & (b) observed the 3-phase injection current, and the injected harmonic exposed in Fig.11 (a). The THD is 3.98 % and fundamental frequency is at 50 Hz 5.132, exposed in Fig. 11(b). Ability of real and reactive power through the grid, input current and input voltage is exposed in Fig.12, the output dc voltage is the power flow control (PFC).



(a) (b)

Fig. 11(a) with harmonics injection and (b) Fundamental Frequency of Grid connected mode

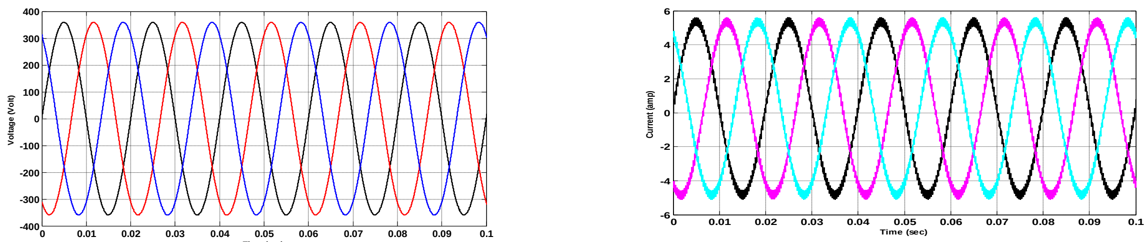


(a) (b)

Fig. 12 (a) Input voltages and input current and (b) DC output voltage

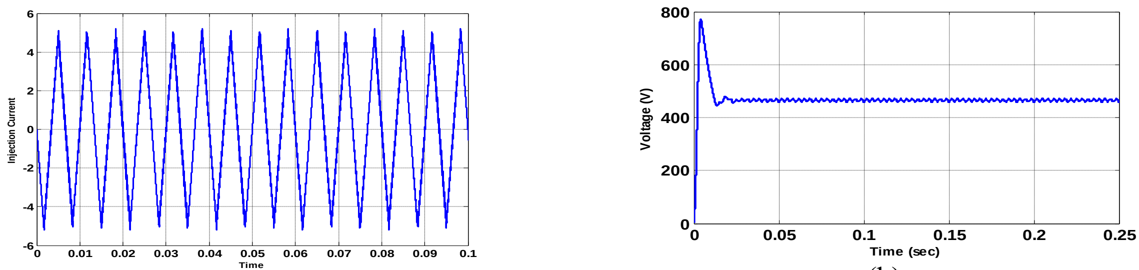
4.2. Case-3 Performance test under Connected DC Motor

In case 3 the 3-phase main current and voltage waveforms is exposed in fig. 13. The main proposed harmonic injection current and dc motor output voltage is shown in fig 14, and calculated the injection harmonic current and voltage is exposed in fig. 15(a). The output of dc motor drive of the armature current, filed current, speed and duty ratio is calculated waveforms is exposed in fig 16, in this process the calculated THD of 3.98% and a PFC is 0.99 have been measured, the frequency is 50 Hz 5.132, THD is 3.98 % exposed in fig 15(b).



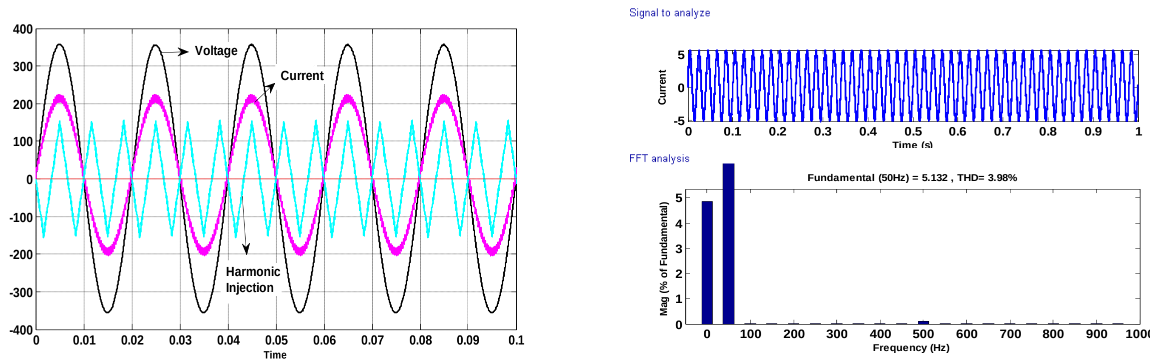
(a) (b)

Fig. 13 under dc motor drive (a)3-Phase Voltage and (b)3-Phase Current



(a) (b)

Fig. 14 (a) Proposed Injection Harmonic and (b) Output DC voltage



(a) (b)

Fig. 15 (a) with harmonics injection and (b) Fundamental frequency of dc motor drive

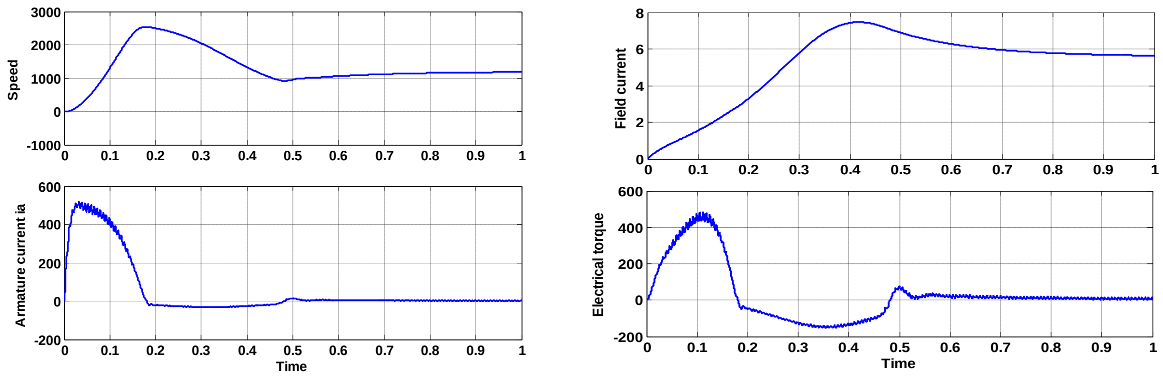


Fig. 16 output DC motor Drive of speed, armature current, field current and torque

5. Conclusion

In this paper the Swiss rectifier is based on harmonic current injection methods on power flow control and implementation of Power factor correction (PFC), Rectifier, the harmonic mitigating PWM technique is used to reduce the harmonics and improve power quality. The renewable sources are used to supply the DC voltage and the power converter used for the power regulation. The DC link is regulating the power and stabilizes the power flow control. The Swiss rectifier is on harmonic current an injection for grid connected and connected to DC motor methods has been tested. The suitable modulation PWM control has been used in this system. The 50 Hz 5.184 at frequency and THD is 3.98 %.

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Authors Bibliography

Maloth Naresh received the Bachelor of Technology Degree in Electrical and Electronics Engineering from Indur Institute of Engineering and Technology, Siddipet, India, in 2012 and the Master of Technology degree in Power System from the MNNIT Allahabad, India, in 2014, currently working towards the Ph.D. degree in the area of Power Electronics application in Power System and renewable energy grid integration in NIT Allahabad. Research interests include Power flow control and power quality issues in distributed generation system (Wind, Solar energy system) in DC-microgrids, analysis of wind power plants

Prof. Ramesh Kumar Tripathi has obtained Bachelor degree in Engineering from REC Durgapur, West Bengal in 1989, M.Tech. from IT-BHU, Varanasi in 1991 and Ph.D. from IIT Kanpur in 2002. He is Fellow IE and senior member IEEE. Presently he is working as Professor in Department of Electrical Engineering, MNNIT Allahabad, India. He has more than 25 years of academic experience. He has many research publications in journals and conferences of international repute. His research interests are Power Electronics Switch-Mode Rectifiers and Power Supplies, Magnet Load Power Supplies, Power Factor Correction, Electrical Drives, Power Quality, Active Power Filters and Virtual Instrumentation