SPWM Based IMC Interfaces for DERs Power Quality Improvement

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***Abstract*—This paper presents about Indirect Matrix Converters (IMC) scheme to enhance the power quality and reliability of the M.G (micro grid) system. The proposed topology comprises with two inverters, which are used for the M.G (micro grid) to exchange power generated by the DERs (i.e., distributed energy resources) that also compensates the load [1]. The control algorithms are developed using SPWM theory (Sinusoidal Pulse Width Modulation) to operate IMC in grid sharing and grid injecting modes. The proposed topology which increases the lower bandwidth, reliability, main inverter requirement, and cost is low due to less in filter size, and better utilization of M.G (micro grid) power while using reduced dc-link voltage rating for the main-inverter[2],[3]. These features make the IMC scheme a promising option for M.G (micro grid) supplying sensitive loads. The proposed topology and control algorithm are validated through extensive MATLAB simulation results.**

Keywords— Indirect Matrix Converter, Grid, Harmonic Distortion, SPWM, Power Quality

I. Introduction

Traditional VSI (voltage source inverters) and CSI (current source inverters) are replaced by proposed topology IMC (Indirect Matrix converters) because of its effective advantages like it satisfies all the requirements of the conventionally used inverter/dc link/rectifier structures that provide an effective way to convert electrical power for motor drives, UPS, VF generators & reactive energy control. The proposed technique (generation matrix converter) has desirable characteristics such as bidirectional energy flow capability; with minimum high order harmonics & no sub sequential harmonics, sinusoidal waveforms are produced, controllable input P.F (power factor), with minimum energy storage requirements, etc.,[4]. The Indirect Matrix Converter (IMC) has more potential than the conventional VSI(voltage source inverters), which are the following unity input P.F at the input side, availability of regular zero speed operation because no current concentrates in any of switches, which has compact design and long life[5]. Some limitations are the number of voltage transfer ratio has a final value of 0.866; it is sensitive to the power storage distortion because of the direct connection between input and output terminal sides [6]. A current - fed system at the input terminal side & a voltage- fed system at the output terminal side because of its inherent bi-directionality and symmetric nature, a dual connection might also feasible for the indirect matrix converter [7]. Capacitive filter on the output terminal side and the inductive filter on the input terminal side are used. The SPWM (sinusoidal pulse width modulation) which is used to control the inverter output voltage and frequency [8]. The required sinusoidal outputs that can be obtained by selecting the switching-States of a 3-ϕ IMC (indirect matrix converter) and calculate their corresponding on time duration. In this paper, DER fed by indirect matrix converter with a SPWM was proposed [9], [10]. Mathematical analysis for the circuit with the duty cycle calculations (switching algorithm) are obtained for both voltage transfer ratios i.e. (0.5) and (0.866). The Simulink model is simulated by using math-operators, relational-operators, and delay circuits. Finally, the proposed model is obtained by using a 3-ϕ RL load [11].

II. Modelling Of The Matrix Converter With Spwm

A. *Sinusoidal Pulse Width Modulation*

Figure. 1 shows the proposed topology of Sinusoidal Pulse Width Modulation Indirect Matrix Converter, it is structured of three rows and three lines, the rows and lines which are linked with bidirectional switches, $i \in (A,B,C)$, $j \in (a,b,c)$. Three-phase input voltages are connected from *a*, *b*, *c*, and the desired output voltages are obtained from *A*, *B*, *C [12], [13]*. Depend on the methods of virtual rectifying & indirect frequency conversion, it is equal to cascade circuit of voltage source rectifying (VSR) and voltage source inverting (VSI) [14]. To get maximum rate of voltage and the most sophiscated virtual direct output current, the rectifying link is idealized into uncontrolled mode of rectifying. The high phase and the low phase switches of 3-phase input voltages should work.

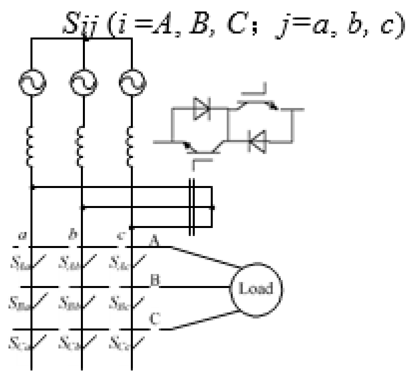
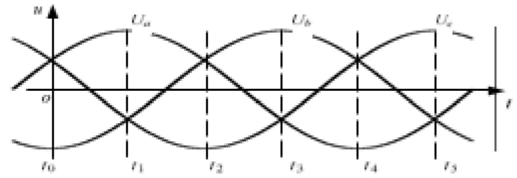
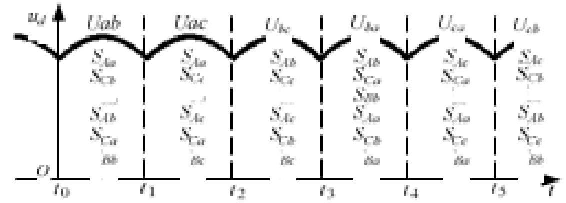


Fig. 1. The proposed of 3-phase to 3-phase IMC. *(Indirect matrix converter)*

Here taking example as the time period [*t*0, *t*1], *S*Aa, *S*Cb, *S*Ba, *S*Ab, *S*Ca, *S*Bb work in the corresponding with controlled strategy, at the time other period of times are analyzed. Fig. 2 shows the wave forms of virtual link [15].



(a) Waveforms of three-phase input



(b) Waveforms of three-phase virtual rectifying output

Fig. 2. Waveforms of three phase input voltages and virtual dc-link.

The conditions are under normal rectifying side switch function is given as:

$$S_{rec}(\omega_i t) = [r_a r_b r_c] = P[\cos\omega_i t \ \cos(\omega_i t - 120) \ \cos(\omega_i t + 120)] \quad (1)$$

Settings of the 3-phase inputs are as below:

$$u_i(\omega_i t) = [u_a u_b \quad u_c]^T = U_{im}[\cos(\omega_i t - \varphi_i) \ \cos(\omega_i t - \varphi_i - 120) \ \cos(\omega_i t - \varphi_i + 120)]^T \quad (2)$$

Now, direct current and voltage of virtual rectifying is given as:

$$U = [S(\omega t)] \times [u(\omega t)] \quad (3)$$

The virtual direct current link is uncontrolled rectifying, its output is the mean value of 3-phase uncontrolled rectifying $3\sqrt{3}\ U_{im} / \pi$[12], then $p = 23 / \pi$. If the switch function of inverter is given as:

$$S_{INV}(w0\ t) = ma[\cos\omega_i t \ \cos(\omega_i t - 120) \ \cos(\omega_i t + 120)] \quad (4)$$

Then, the required Alternating Current voltage output of Sinusoidal Pulse Width Modulation IMC (indirect matrix converter) is expressed as:

$$U0\ (w0\ t) = [S_{INV}(w0\ t)].Ud\ 3\sqrt{3}\ U_{im} / \pi\ ma\ \cos\phi i\ [\cos\omega_i t \ \cos(\omega_i t - 120) \ \cos(\omega_i t + 120)] \quad (5)$$

Where, U_{im} is input phase voltage amplitude, φ_i is the input side voltage & current phase difference, m_a is the modulation index, ω_0 is the output AC voltage of angle frequency, φ_0 is the output voltage original phase angle. The above equation, we can adjust m_a、ω_0、φ_0 to obtain the required output of AC, & ω_0 (output frequency) is not related with the ωI (input frequency), output frequency (ω_0) not is only will be less than power supply frequency, sometimes may also be higher it, from theory, it is not a upper limit, which virtual DC link voltages include six times of power supply frequency pulse components [16]. Virtual DC voltage (i.e. line voltage envelope) envelope u_d is given as:

$$Ud = \sqrt{3}Uim \cos(wi\ t + 2\pi/3.k) \quad (6)$$

Where k=1,2,…, t∈[(-π/3wi, π/3wi)]

Its pulse index is:

$$S_u = \frac{\sqrt{3}U_{im}\frac{\pi}{m}\sin(\frac{\pi}{m})\frac{2}{m^2-1}}{\sqrt{3}U_{im}\frac{\pi}{m}\sin(\frac{\pi}{m})} = \frac{2}{m^2-1} = 5.7\%, \quad m = 6 \quad (7)$$

It is obvious that, even if in balanced 3-phase input, for the fluctuating of virtual DC, the virtual inverting output must be subjoined 5.7 percent modulation amplitude, the power supply character is deteriorates by it [17]. The electric abnormal network often appears, so the compensation adoption is necessary. And after, we are introducing a new compensation method is feed forward control.

Control Strategies of Feed-Forward Compensation

The Sinusoidal Pulse Width Modulation method is based on principle of area equivalence. In figure.3, in a Ts (switch period), the area of expected output sine wave is given as:

$$A_r = U_{om}\int_{t_k}^{t_{k+1}} \sin\omega_0 t dt = \frac{U_{om}}{\omega_0}[\cos(\omega_0 t_k - \cos(\omega_0 t_{k+1})]$$
$$t \in [t_k, t_{k+1}], k = 1, 2, \cdots, m_f \quad (8)$$

Where mf, frequency modulation rate (mf). The input of conventional inverter is ideal DC Ud, the product of the modulated high frequency breadth (Δ t) and Ud should equal to Ar. The equations are given as:

$$U_d\Delta t = \frac{U_{om}}{\omega_0}[\cos(\omega_0 t_k) - \cos(\omega_0 t_{k+1})]$$
$$\Delta t = \frac{U_{om}}{U_d\omega_0}[\cos(\omega_0 t_k - \cos(\omega_0 t_{k+1})] \quad (9)$$

When smooth ideal DC high voltage (Ud) is to control of inverters only use ma for the steady state. Even as the described in the second section, even the symmetrical conditions if the AC input of indirect matrix converter, the virtual DC output also includes low frequency pulse components of 300Hz (input frequency is 50Hz), and it will affect the output character of matrix converter. When the input is unbalance or non-sine, the influences will be worse. Here, Ud of equation (9) should be exchanged to ud [18], [19]. For compensating the influences of ud pulse, when ud becomes high, modulation pulse breadth Δt should become narrow, or else, it should become broad. Modulation pulse breadth is not conventional Δt, but Δt′ in the fig.3. So we need introduce a prior modulating index mcp, it is used to compensate change of virtual DC. Prior modulating index mcp will prior modulate the amplitude of carrier, this function will be achieved by prior modulator. Fig. 4 shows the sketch map [20] [21].

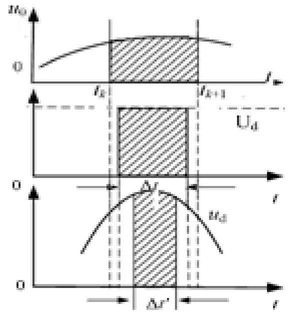


Fig. 3. Area equivalence principle of SPWM.

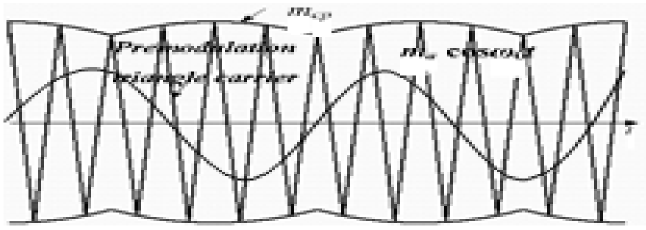


Fig. 4. Prior modulation waveform of modulation-wave.

B. Matrix Converter Switching Principle

The three-phase indirect matrix converter (IMC) proposed topology is shown in Fig. 5.

Since (IMC) indirect matrix converter by using nine bidirectional switches connects load directly to the voltage source, must never short the input phases, because, due to its inductive nature of the load, the output phases must not be left open. The switching function of a switch is shown:

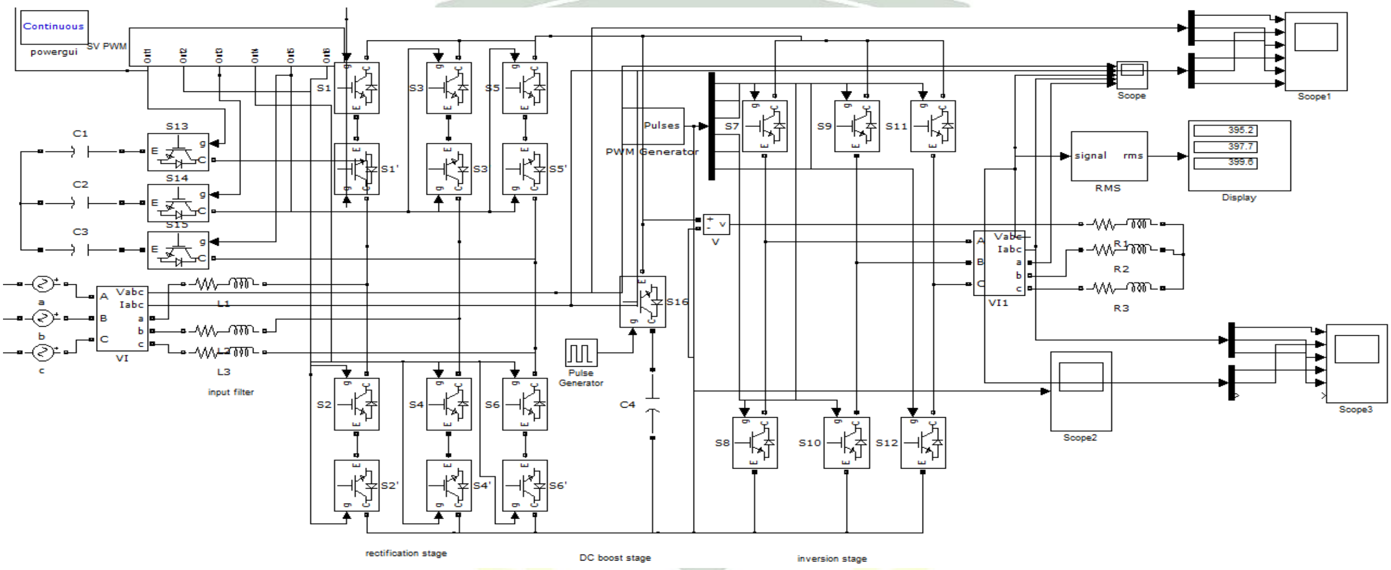


Fig. 5. Three-phase Sinusoidal Pulse Width Modulation based Indirect Matrix Converter.

$$S_{ij} = \begin{cases} 1, & S_{ij} \text{ close} \\ 0, & S_{ij} \text{ open} \end{cases} \quad i \in \{u, v, w\}, j \in \{a, b, c\}$$

The constraints can be expressed as

$$S_{ia} + S_{ib} + S_{ic} = 1, \quad (10)$$

For a three-phase Indirect Matrix Converter (IMC) there are twenty seven (27) valid switch-combinations giving thus twenty seven (27) voltage vectors are shown in the below Table 1. The switching-combinations are classified into three groups they are, stationary vectors, synchronously rotating vectors and zero vectors.

Table 1: Matrix converter switching vectors

Group	ON Switch			V_u	V_v	V_w	I_a	I_b	I_c	V_O	ω_O	I_i	ω_i
I	S_{au}	S_{bv}	S_{bw}	V_a	0	$-V_a$	I_u	$-I_u$	0	$^2/_{3V_a}$	0	$^2/\sqrt{3i_u}$	$-\pi/6$
	S_{bu}	S_{av}	S_{aw}	$-V_a$	0	V_a	$-I_u$	I_u	0	$-^2/_{3V_a}$	0	$-^2/\sqrt{3i_u}$	$-\pi/6$
	S_{bu}	S_{cv}	S_{cw}	V_b	0	$-V_b$	0	I_u	$-I_u$	$^2/_{3V_b}$	0	$^2/\sqrt{3i_u}$	$\pi/2$
	S_{cu}	S_{bv}	S_{bw}	$-V_b$	0	V_b	0	$-I_u$	I_u	$-^2/_{3V_b}$	0	$-^2/\sqrt{3i_u}$	$\pi/2$
	S_{cu}	S_{av}	S_{aw}	V_c	0	$-V_c$	$-I_u$	0	I_u	$^2/_{3V_c}$	0	$^2/\sqrt{3i_u}$	$7\pi/6$
	S_{au}	S_{cv}	S_{cw}	$-V_c$	0	V_c	I_u	0	$-I_u$	$-^2/_{3V_c}$	0	$-^2/\sqrt{3i_u}$	$7\pi/6$
	S_{bu}	S_{av}	S_{bw}	$-V_a$	V_a	0	I_v	$-I_v$	0	$^2/_{3V_a}$	$2\pi/3$	$^2/\sqrt{3i_v}$	$-\pi/6$
	S_{au}	S_{bv}	S_{aw}	V_a	$-V_a$	0	$-I_v$	I_v	0	$-^2/_{3V_a}$	$2\pi/3$	$-^2/\sqrt{3i_v}$	$-\pi/6$
	S_{cu}	S_{bv}	S_{cw}	$-V_b$	V_b	0	0	I_v	$-I_v$	$^2/_{3V_b}$	$2\pi/3$	$^2/\sqrt{3i_v}$	$\pi/2$
	S_{bu}	S_{cv}	S_{bw}	V_b	$-V_b$	0	0	$-I_v$	I_v	$-^2/_{3V_b}$	$2\pi/3$	$-^2/\sqrt{3i_v}$	$\pi/2$
	S_{au}	S_{cv}	S_{aw}	$-V_c$	V_c	0	$-I_v$	0	I_v	$^2/_{3V_c}$	$2\pi/3$	$^2/\sqrt{3i_v}$	$7\pi/6$
	S_{cu}	S_{av}	S_{cw}	V_c	$-V_c$	0	I_v	0	$-I_v$	$-^2/_{3V_c}$	$2\pi/3$	$-^2/\sqrt{3i_v}$	$7\pi/6$
	S_{bu}	S_{bv}	S_{aw}	0	$-V_a$	V_a	I_w	$-I_w$	0	$^2/_{3V_a}$	$4\pi/3$	$^2/\sqrt{3i_w}$	$-\pi/6$
	S_{au}	S_{av}	S_{bw}	0	V_a	$-V_a$	$-I_w$	I_w	0	$-^2/_{3V_a}$	$4\pi/3$	$-^2/\sqrt{3i_w}$	$-\pi/6$
	S_{cu}	S_{cv}	S_{bw}	0	$-V_b$	V_b	0	I_w	$-I_w$	$^2/_{3V_b}$	$4\pi/3$	$^2/\sqrt{3i_w}$	$\pi/2$
	S_{bu}	S_{bv}	S_{cw}	0	V_b	$-V_b$	0	$-I_w$	I_w	$-^2/_{3V_b}$	$4\pi/3$	$-^2/\sqrt{3i_w}$	$\pi/2$
	S_{au}	S_{av}	S_{cw}	0	$-V_c$	V_c	$-I_w$	0	I_w	$^2/_{3V_c}$	$4\pi/3$	$^2/\sqrt{3i_w}$	$7\pi/6$
	S_{cu}	S_{cv}	S_{aw}	0	V_c	$-V_c$	I_w	0	$-I_w$	$-^2/_{3V_c}$	$4\pi/3$	$-^2/\sqrt{3i_w}$	$7\pi/6$
II	S_{au}	S_{av}	S_{aw}	0	0	0	0	0	0	0	-	0	-
	S_{bu}	S_{bv}	S_{bw}	0	0	0	0	0	0	0	-	0	-
	S_{cu}	S_{cv}	S_{cw}	0	0	0	0	0	0	0	-	0	-
III	S_{au}	S_{bv}	S_{cw}	V_a	V_b	V_c	I_u	I_v	I_w	V_i	$\omega_i t$	i_o	$\omega_o t$
	S_{au}	S_{cv}	S_{bw}	$-V_c$	$-V_b$	$-V_a$	I_u	I_w	I_v	$-V_i$	$-\omega_i t + 4\pi/3$	i_o	$-\omega_o t$
	S_{bu}	S_{cv}	S_{aw}	$-V_{ab}$	$-V_{ca}$	$-V_{bc}$	I_v	I_u	I_w	$-V_i$	$-\omega_i t$	i_o	$-\omega_o t + 2\pi/3$
	S_{bu}	S_{av}	S_{cw}	V_b	V_c	V_a	I_w	I_u	I_v	V_i	$\omega_i t + 4\pi/3$	i_o	$\omega_o t + 2\pi/3$
	S_{cu}	S_{av}	S_{bw}	V_c	V_a	V_b	I_v	I_w	I_u	V_i	$\omega_i t + 2\pi/3$	i_o	$\omega_o t + 4\pi/3$
	S_{cu}	S_{bv}	S_{aw}	$-V_b$	$-V_a$	$-V_c$	I_w	I_v	I_u	$-V_i$	$-\omega_i t + 2\pi/3$	i_o	$-\omega_o t + 4\pi/3$

III. SIMULATION RESULTS

The proposed simulation results are obtained for the indirect matrix converter simulation circuit is described here. The chapter is described as two sections; a section that explains the simulation-results of the indirect matrix converter proposed method. The results of simulation of this topology are presented to give the comparison of the disadvantages and advantages, although to verify whether the required characteristics of the IMC (indirect matrix converter) proposed topology can be achieved by this topology. Fixed duty cycles that results controllable voltage level and only 50 Hz output frequency, and transfer function is proposed to calculate variable duty cycles, and same were applied. At the same time those variable duty cycles are used to generate a controlled output voltage level & a controlled output frequency range. Simulation-results of the IMC (indirect matrix converter) method are examined. Finally, here the results are improved power quality of the IMC (indirect matrix converter are presented) [26].

A. *Simulation Results of the IMC (Indirect Matrix Converter)*

The Indirect Matrix Converter (IMC) circuit of the 3-phase to 3- phase AC/DC/AC IMC (indirect matrix converter) setup is shown in Fig. 3. In the IMC for the ideal switches of the converter, four different type of modulation-transfer functions of generating the control switching-signals were applied. They are a combined transfer function and a forward transfer function, a reversed transfer function, with 50% maximum gain, which is able to control to unity of the input phase shift of the converter & final transfer function with maximum gain 86.67%, as well able for unity to control the input phase shift of the converter. All four (4) transfer functions which are proposed. Table 2 shows the specifications of the 3-phase to 3-phase IMC (indirect matrix converter) circuit.

TABLE II. INPUT-OUTPUT SPECIFICATIONS OF THE IMC (INDIRECT MATRIX CONVERTER)

Symbol	Parameter	Value	Unit
3ϕVi	Input Supply Voltage	400	V
fin	Input frequency	50	Hz
Lin	Input Inductance	200	μH
Cin	Input Capacitance	50	μF
Rin	Input Resistance	0.02	Ω
3ϕVo	Output Voltage	0.200	V
fo	Output frequency	0.200	Hz
Io	Output Current	0.10	A
RL	Resistive Load	10	Ω
Lo	Output Inductance	2000	μH
Co	Output Capacitance	50	μF
fs	Switching frequency	5	kHz

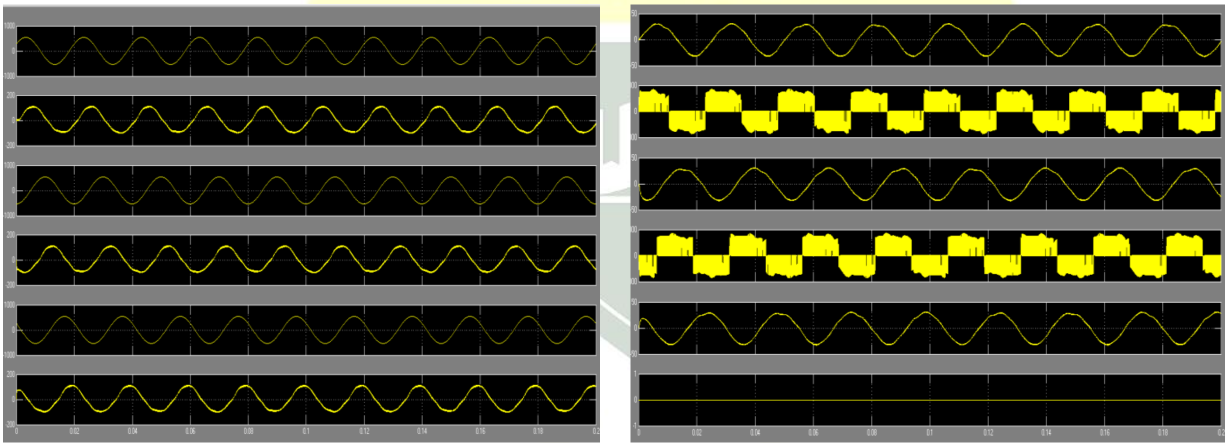


Fig. 6. Output voltage and current, Line-line voltage, Phase-line voltage.

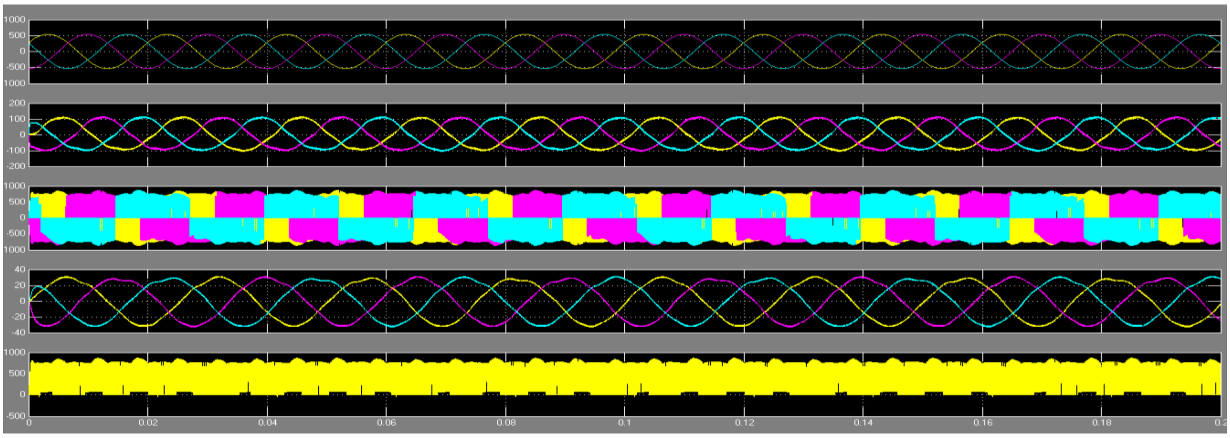


Fig. 7. Output 3 phase voltages & currents of wind generator.

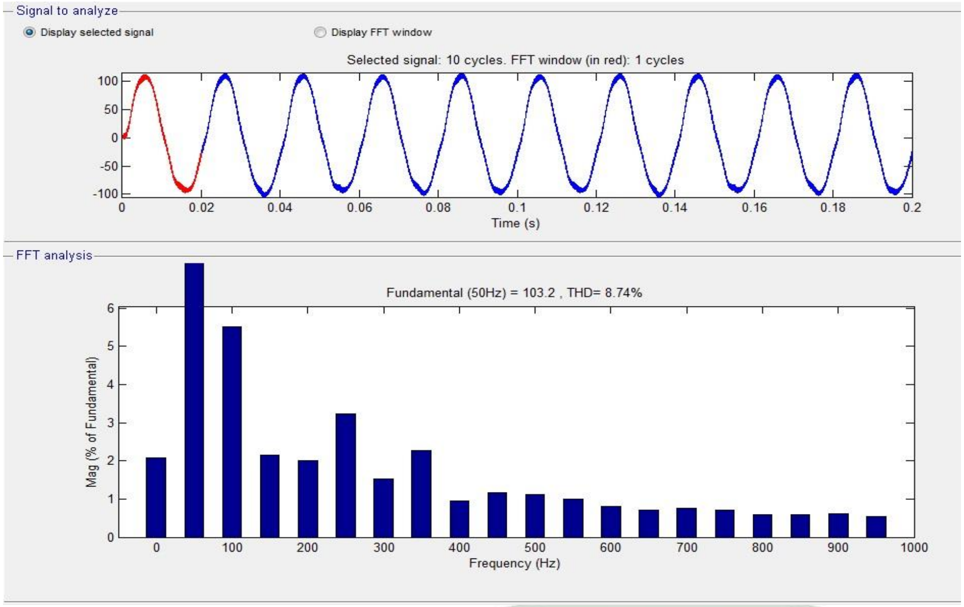


Fig. 8. T.H.D analysis of line current & phase voltages.

CONCLUISON

The IMC (Indirect Matrix Converter) topology described the comparative analysis of variable resistance and inductance using SPWM (Sinusoidal Pulse Width Modulation) Techniques. The DER (Distributed Energy Resource) is connected to a AC-DC-AC Indirect Matrix Converter (IMC) the energy storage elements are not necessary for fed to RL load. From the simulation results, observed that Sinusoidal Pulse Width Modulation (SPWM) is more efficient compared to the other PWM techniques for the proposed topology. Due to reduced number of power electronic switches the efficiency of the proposed converters is expected to be high. Furthermore, there is no longer hazard to shoot through state, so that it improves the reliability for the proposed converters. The proposed converter THD analysis of input and phase voltages, output currents & line currents are obtained highly superiority to the quality of input currents with respect to the over the QZMC. The Conventional DC-link are eliminated in the Indirect matrix converter (IMC) to attain high efficiency and low cost. In future the work is extreme with modeling for variable speed drives.

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