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Shunt and Series Active Filters Based Power Quality Conditioners for Matrix Converter

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Abstract: ***The growing interest in power quality has lead to a variety of devices designed for mitigating power disturbances such as harmonics caused due to different problems. By minimizing the total harmonic distortion the harmonic pollution in the power system will be reduced and power quality will be increased. Matrix converter injects significant and non standard frequency components into power systems. The active filter technology is used to minimize the inductance value. To improve harmonics problem series and shunt active filter is used with matrix converter. A shunt active filter senses the load current and injects a current into the system to compensate current harmonics. A shunt active filter is to be placed in parallel with a load to detect the harmonic current of the load and to inject a harmonic current with the same amplitude of that of the load into the AC system. A series active filter is used to eliminate voltage harmonics produced by the matrix converter. The series converter deals with the input voltage distortions. It injects or receives active power for voltage sag or swell compensation. The proposed approach has been tested and validated on the matrix converter using simulink. The datasheet parameters are included in these models to bring it more close to actual circuit model. Simulated results confirm that the active power filters using series and shunt filter can maintain high performance for matrix converter.***

Keywords: Matrix Converter, series active filter, shunt active filter, passive filter, power quality, Total Harmonic Distortion(THD), Switching error.

I.INTRODUCTION

Power quality is defined as set of limits or conditions that allows electrical devices to function in their planned manner without loss of performance. Without proper power the load may malfunction, fail permanently or not operate well. Ideally voltage is fed by utility as sinusoidal having voltage and frequency given by international standards and the disturbance in power quality can be produced by inverters and converters. The beginnings of the Matrix Converter date back to the late 1970s.[2]

Nowadays, the name “Matrix Converter” is used to label any power topology that can be organized into sub blocks placed in a matrix shape. The matrix converter is the 3 phase to 3 phase and is just one of the possible direct A.C-A.C converter topology .The matrix converter has several advantages over traditional rectifier-inverter type power frequency converters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics. The Matrix Converter requires a bi-directional switch capable of blocking voltage and conducting current in both directions.[1] Unfortunately there are no such devices currently available, so discrete devices need to be used to construct suitable switch cells and therefore discrete unidirectional devices are arranged. It has inherent bidirectional energy flow capability and the input power factor can be fully controlled. Also it has minimal energy storage requirements, which allows to get rid of bulky and lifetime-limited energy-storing capacitors. The Matrix Converter is a single stage converter which has an array of mxn bidirectional power switches to connect, directly, an m-phase voltage source to an n-phase load.[4] The Matrix Converter of 3x3 switches, shown in figure 1, has the highest practical interest because it connects a three-phase voltage source with a three-phase load. Defining the switching function of a single switch as

$$S_{kj} = \begin{cases} 1 \text{ Switch } S_{kj} \text{closed} & k=A,B,C \\ 0 \text{ Switch } S_{kj} \text{open} & j=a,b,c \end{cases} \quad (1)$$

Where A, B, C are input phase and a,b,c are output phases.

The constraints discussed above can be expressed by

$$S_{Aj} + S_{Bj} + S_{Cj} = 1 \qquad j= a,b,c \quad (2)$$

With these restrictions, the 3x3 Matrix converters has 27 possible switching states

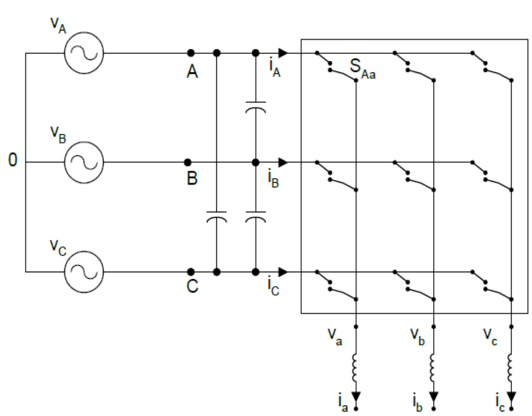

Fig.1. Simplified circuit of a 3x3 Matrix Converter.

Normally, the Matrix Converter is fed by a voltage source and for this reason; the input terminals should not be short-circuited. On the other hand, the load has typically an inductive nature and for this reason an output phase must never be opened. The matrix converter needs to be protected against the overvoltage and over current that might be destructive for its semiconductor devices. An effective and robust protection scheme plays an important role in the implementation of stable and reliable power converter. With respect to an A.C. drive application of the matrix converter, overvoltages can originate externally as voltage surge existing on to the A.C. mains or internally as a consequence of switching commutation error.[5] The clamp circuit is operative for all nine bi-directional switches. It protects the switches from surge coming out from the input A.C line as well as from outside produced whenever the emergency shutdown of the converter is required. The advantage of protection scheme is simple, small hardware requirement and safe in all operating conditions. But the disadvantage is that it increases the number of semiconductor devices required and also the amount of reactive component needed.

The disadvantage of matrix converter is that it has maximum input output voltage transfer ratio limited to 87% for sinusoidal input and output waveforms. It requires more semi- conductor devices than a conventional A.C-A.C. indirect frequency converter. Since there no monolithic bi-directional switches exist. Finally it is particularly sensitive to the disturbance of input voltage system.

“Harmonics” means a component with a frequency that is an integer multiple (where n is the order of harmonic) of the fundamental frequency; the first harmonic is the fundamental frequency (50 or 60 Hz). The second harmonic is the component with frequency two times the fundamental (100 0r 120 Hz) and so on. Harmonic distortion can be considered as a sort of pollution of the electric system which causes problems if the sum of the harmonic currents exceeds certain limits. The utilization of electrical power mainly depends upon supply of power with controllable frequencies and voltages, where as its generation and transmission takes place at nominally constant levels. So to convert nominal frequency to variable frequency power electronics circuitry (non-linear loads) is needed, which distorts the voltage and current waveforms. Therefore, the main source of harmonics in the power systems is the non linear loads. [1-3]

The total harmonic distortion (THD), of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Harmonic distortion is caused by the introduction of waveforms at frequencies in multiples of the fundamental i.e. 3rd harmonic is three multiplied by the fundamental frequency (150Hz). THD is a measurement of the sum value of the waveform that is distorted. The THD is a very useful quantity for many applications. It is the most commonly used harmonic index. However, it has the limitation that, it is not a good indicator of voltage stress within a capacitor because that is related to the peak value of voltage waveform.

$$THD = \frac{\sqrt{\left(V_2^2 + V_3^2 + \ldots\ldots + V_N^2\right)}}{V_1}$$

The advantage of Active filters over passive filter are:

- Inductors can be avoided. Passive filters without inductors cannot obtain a high Q (low damping), but with them are often large and expensive (at low frequencies), may have significant internal resistance, and may pick up surrounding electromagnetic signals.
- The shape of the response, the Q (Quality factor), and the tuned frequency can often be set easily by varying resistors, in some filters one parameter can be adjusted without affecting the others. Variable inductances for low frequency filters are not practical.

The amplifier powering the filter can be used to buffer the filter from the electronic components it drives or is fed from, variations in which could otherwise significantly affect the shape of the frequency response.

II. General compensation Technique of Matrix Converter

2.1. General Structure. A matrix converter is a variable amplitude and frequency power supply that converts the three-phase line voltage directly, that is without, intermediate DC-voltage or current link, into three-phase output voltage. It is very simple in structure and has powerful controllability. The converter consists of nine modular H-bridge capacitor clamped switch cells that are connected from each input phase to each output phase. The terminal AC voltages of the Converter is synthesized from the modulation techniques of Space Vector Modulation. The space vector modulation approach is a well-known technique for control of three phase converters. The switching pulses for the power devices in each bridge are obtained from the modulation techniques. The converter is capable of both increasing and decreasing the voltage magnitude and frequency, while operating with arbitrary power factors. Multilevel switching can be used to synthesize the voltage waveforms at both the input and output of the converter. The switch cells can be connected in series with branch of the matrix to increase the voltage rating of the converter. The converter is capable of increasing the number of levels of operation by connecting more than one switch cell in series.

Passive Filter Compensation. The principal method of reducing the harmonics generated by the static converter is provided by the input filter using reactive storage elements as shown in Figure 2. So many configurations are proposed for the matrix converter input filter. Such differences are a consequence of different design criteria, or at least differently weighted, different switching frequencies, and different modulation strategies. In order to meet the required attenuation requirement, there is an overall increase in filter size. Moreover, the input filter output impedance, related to the total filter capacitor value, is more difficult to control and leads to converter instability. As far as the matrix converter is concerned, a high displacement angle of the input line current due to the input filter capacitance component might be compensated by the matrix converter, setting as reference for the input current a lagging displacement angle. But in this way the maximum voltage transfer ratio for the converter will be significantly reduced. Therefore, even for the matrix converter, the upper limit of the input filter capacitance is set by the minimum acceptable AC main power factor. Similarly the control of the impedance interaction between the input filter and the voltage converter is necessary. In general, the filter output impedance should be as low when compared to the converter input impedance. The filter output impedance can be reduced by the filter capacitor size that may increase practically the impedance interaction constraint which determines the lower constraint on the filter capacitor value. In addition to the above proper filter pole damping is extremely important for achieving low-filter output impedance for all frequencies, and, the overall system stability may be improved. In general, an optimized design of the matrix converter input filter is a quite difficult task,since it relies on a system level approach.

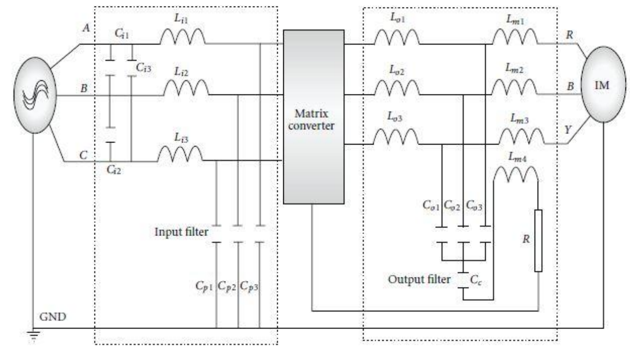

Fig.2.Existing technique of power quality improvement for the matrix converter.

III. The Proposed Compensation Scheme for Matrix Converter

The proposed technique includes two parts: the first part compensates matrix converter's input power quality problems and the second part compensates matrix converter's output power quality problems. The matrix converter is considered as two types of load, that is, Current-Source Type of Harmonic Sources, Voltage-Source Type of Harmonic Sources. The enhanced control system is proposed to further eliminate harmonics with higher accuracy.

1. Current-Source Type of Harmonic Sources in Matrix Converter. Power electronic converters are a common and typical source of harmonic currents. The distortion of the current waveform, that is, the generation of harmonics, results from the switching operation. Because the harmonic current contents and characteristics are less dependent upon the AC side, this type of harmonic source behaves like a current source. Therefore, they are called current-source type of harmonic source (or harmonic current source) and represented as a current source. A shunt active filter is to be placed in parallel with a load (matrix converter) to detect the harmonic current of the load and to inject a harmonic current with the same amplitude of that of the load into the AC system. In order not to lose generality, the harmonic current source is represented as Norton's equivalent circuit.

2. Voltage-Source Type of Harmonic Sources in Matrix Converter. Another type of common harmonic source is matrix converter output, which produces harmonic voltage and current waveforms. Although the current is highly distorted, its harmonic amplitude is greatly affected by the impedance of the AC side. Therefore, the matrix converter output behaves like a voltage source harmonic. The harmonic voltage source is represented as Thevenin's equivalent circuit, as shown in Figure 6. A pure voltage-source type of harmonic source is a special case of Thevenin's equivalent with $Z_L \rightarrow 0$.

IV. Simulations Results

1. SIMULATION RESULTS WHEN HARMONICS PRESENT IN SUPPLY:

The results show that the THD can be reduced with the help of series and shunt active filters. The comparison of THD is done between matrix converter without filter and with filter both when harmonics is induced in the supply or when switching error occurs.

SYSTEM PARAMETERS**:** The system parameters considered for the study and comparison of THD of matrix converter in different cases are

Case(A): Matrix converter without the use of series and shunt filters i.e in ideal condition.

TABLE 1.Parameters for Case (A)

	System Parameters	**Value**
1	AC voltage source	100 (peak)
2	Frequency	60 Hz
3	Resistance	2 ohm

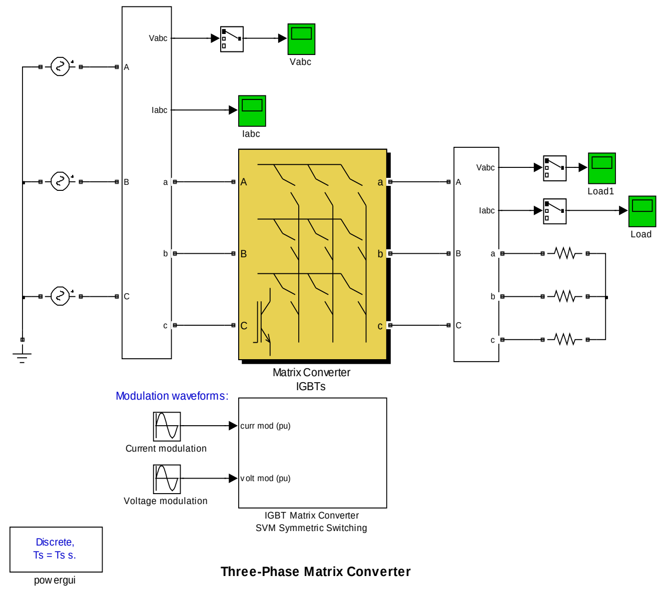

Fig.3. Three Phase Matrix Converter without Filter

Case(B): Matrix converter with use of series and shunt active filters and if harmonics is not induced in it.

TABLE 2. Parameters for Case (B)

	System Parameters	**Value**
1	AC voltage source	100 (peak)
2	Harmonics induced	100
3	Frequency	60 Hz
4	Resistance	2 ohm
5	Inductance	1e-4 henry
6	Capacitance	1e-6 Farad
7	Linear transformer-windings 1	[1 0.002 .08] [V R L]
8	Linear transformer-windings 2	[1 0.002 .08] [V R L]

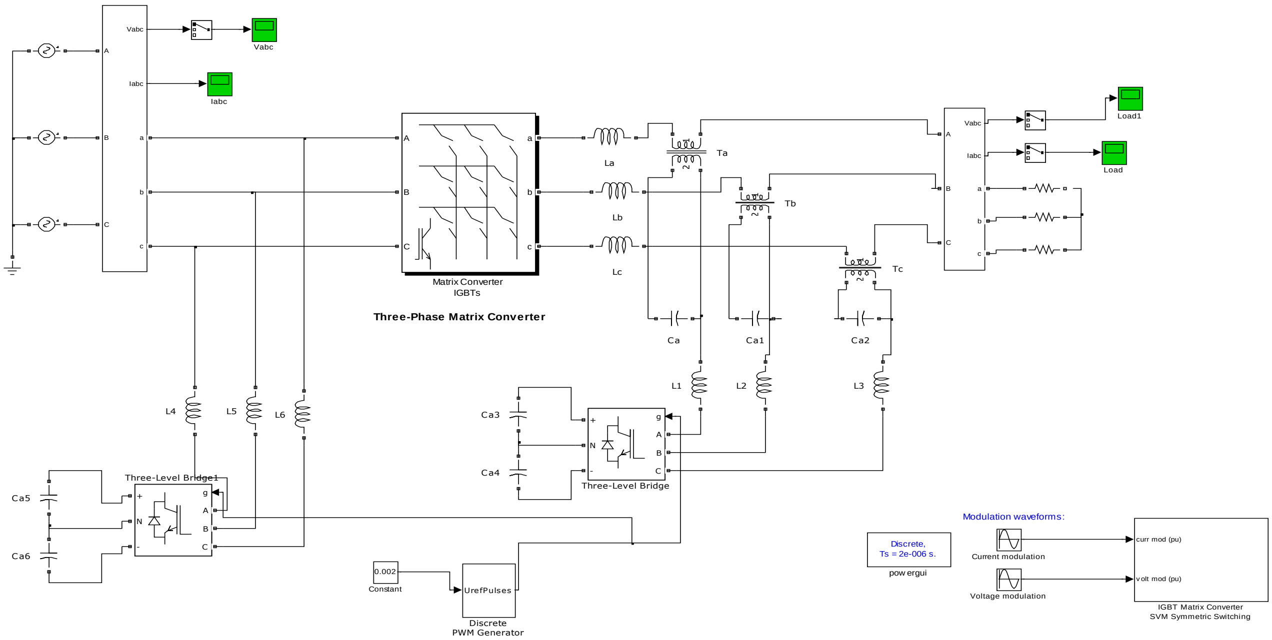

Fig.4 Series and shunt active filter used with matrix converter

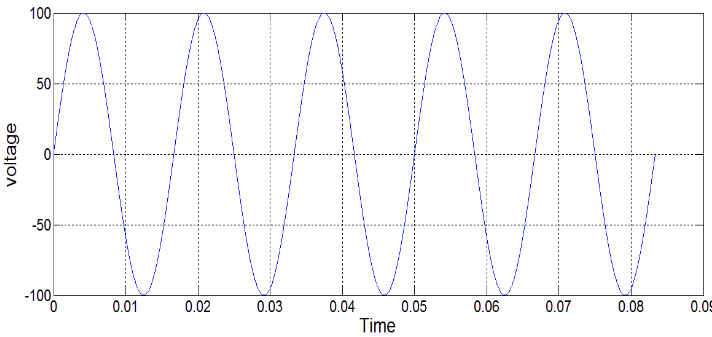

Fig.5 Source Voltage for Case (A)

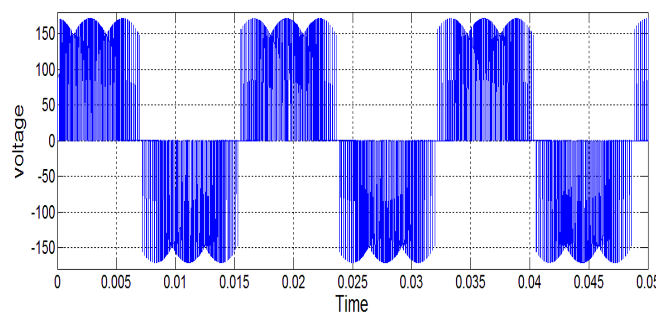

Fig.7 Output Voltage for Case (A)

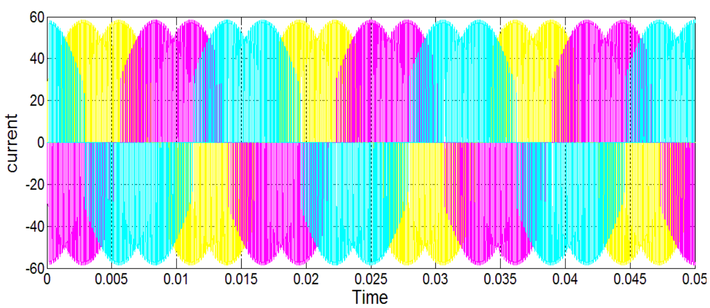

Fig.6 Source Current for Case (A)

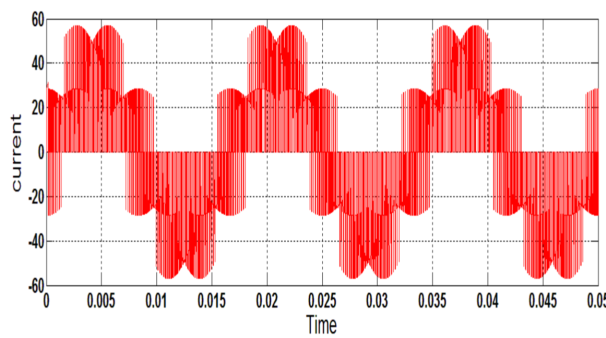

Fig.8 Output Current for Case (A)

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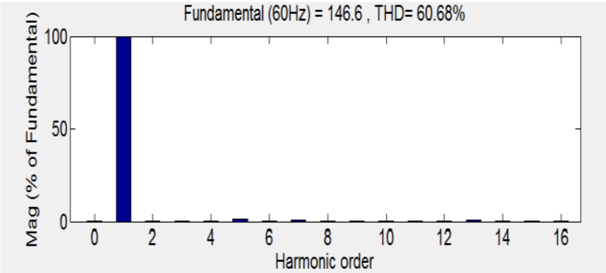

Fig.9 Voltage THD without Filter Case (A)

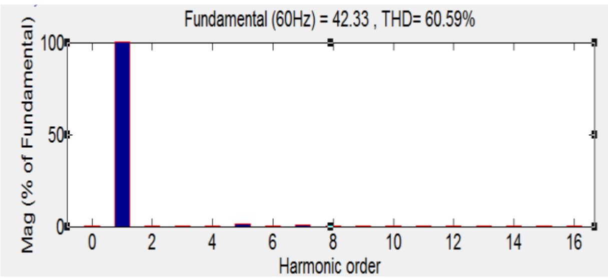

Fig.10 Current THD for case (A)

If 1/3*100 harmonic is induced in the supply.

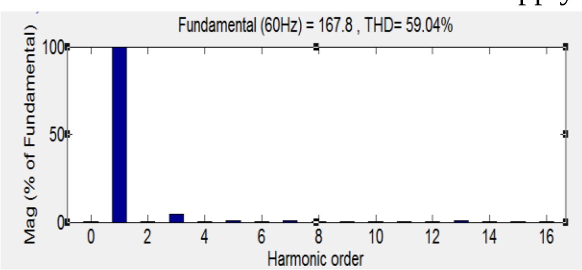

Fig.11 Voltage THD without Filter Case (B)

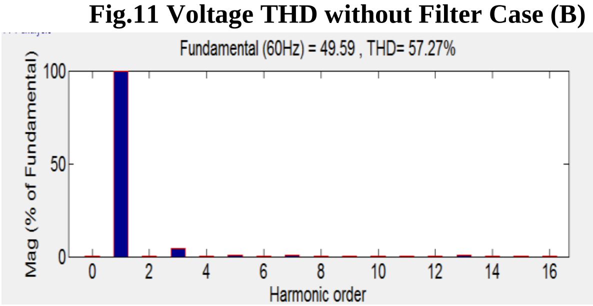

Fig.12 Current THD for case (B)

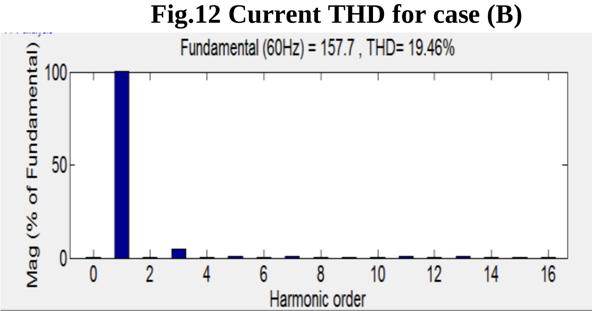

Fig.13 Voltage THD without Filter Case (B)

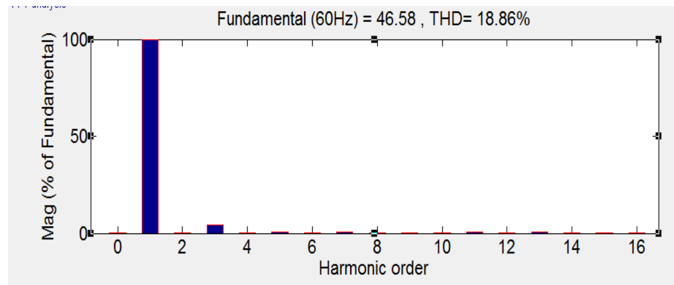

Fig.14 Current THD for case (B)

The result proves that with the help of series and shunt active filters the THD is reduced comparing with that without a filter.

SIMULATION RESULTS WHEN HARMONICS PRESENT IN SUPPLY:

TABLE 3. THD Analysis Due to Harmonics Present In Supply

S.No	Case	Harmonics	%THD Without filter (voltage)	%THD With filter (voltage)	%THD Without filter (current)	%THD With filter (current)
1	I	0	60.68	19.62	60.59	19.59
2	II	1/3*100	59.04	19.46	57.27	18.86
3	III	150/3*100	67.85	37.49	58.58	33.03
4	IV	170/5*100	67.34	36.93	58.16	32.57

2 HARMONICS INDUCED DUE TO ERROR IN SWITCHING:

System Parameters: The system parameters considered for the study and comparison of THD of matrix converter in case of switching error:

CASE(C): Matrix converter without the use of series and shunt filters i.e in ideal condition.

TABLE 4. Parameters for (c)

	System Parameters	Value
1	AC voltage source	100 (peak)
2	Frequency	60 Hz
3	Resistance	2 ohm

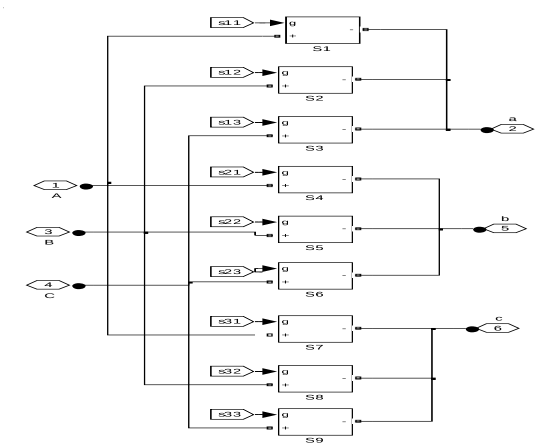

Fig 15 Switching Of Matrix Converter In Ideal Condition

Case(D): Matrix converter without the use of series and shunt filters and if error is induced in switching.

TABLE 5 .Parameters for Case (D)

	System Parameters	Value
1	AC voltage source	100 (peak)
2	Switching error	S12 to S21 and S32 to S23
3	Frequency	60 Hz
4	Resistance	2 ohm

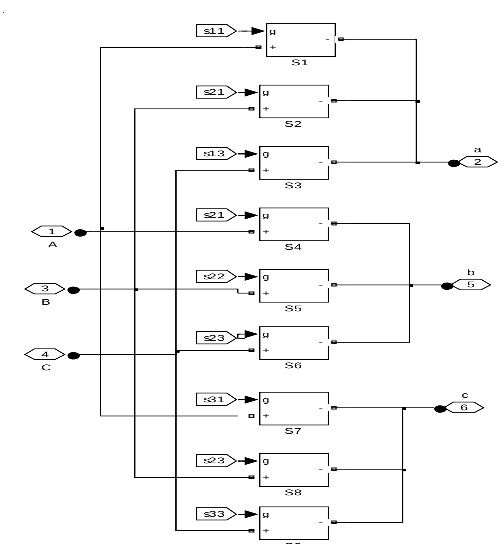

Fig.16 Switching of Matrix Converter with switching error

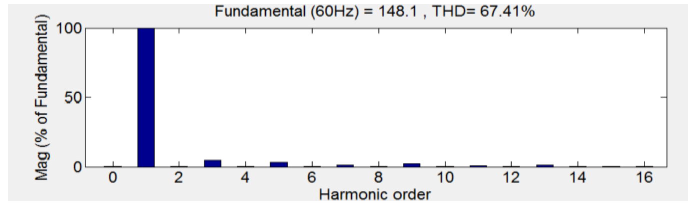

Fig.17Voltage THD without Filter Case (D)

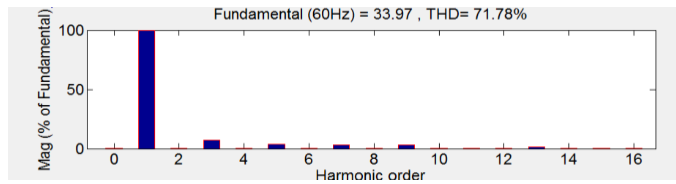

Fig.18 Current THD for case (D)

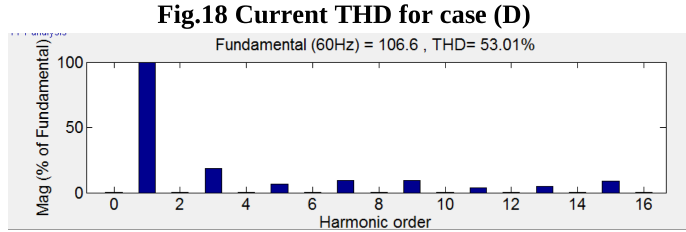

Fig.19 Voltage THD without Filter Case (D)

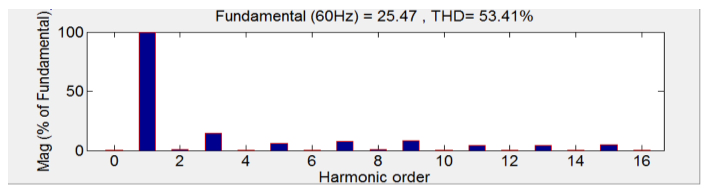

Fig.20 Current THD for case (D)

HARMONICS INDUCED DUE TO ERROR IN SWITCHING:

Table 6 THD Due To Switching Error

S.No	Case	Switching Error	%THD Without filter (voltage)	%THD With filter (voltage)	%THD Without filter (current)	%THD With filter (current)
1	I	0	60.68	19.62	60.59	19.59
2	II	S12-S21, S32-S23	67.41	53.01	71.78	53.41
3	III	S13-S31, S23-	76.82	53.49	72.73	54.41

		S32				
4	IV	S13-S33, S23-S33, S32-S33	60.54	26.50	53.98	21.28

V.CONCLUSION

The proposed Matrix Converter with series and shunt active filter techniques was simulated using Matlab/ Simulink model blocks. THD has been analyzed in detail and the outputs were presented. The result proves that with the help of series and shunt active filters the THD is reduced comparing with that without a filter. It also has the minimum THD level when harmonics or error in switching is present and hence the reduced losses on the drives. It can be implemented by DSP technique for future work.

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