Journal of Engineering and Applied Sciences 6 (5): 289-294, 2011
ISSN: 1816-949X

Matrix Converter is an Efficient Frequency Regulator

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Abstract: The aim of this study is to maintain the constant frequency in the utility using matrix converter. Matrix converter is an ac-ac frequency changing system. In this study, the matrix converter is act as a frequency regulator. This frequency regulator (matrix converter) is used to regulate the supply frequency when it varies beyond the power quality limit. The performance of the frequency regulator (matrix converter) has been verified based on the simulation results using Matlab/Simulink software.

Key words: Matrix converter, frequency regulation, Matlab/Simulink, ac-ac, constant frequency, power quality limit, constant frequency, India

INTRODUCTION

A Matrix Converter (MC) is an array of controlled semiconductor switches that directly connect with each input phase to each output phase without any intermediate dc link. The main advantage of MCs is the absence of bulky reactive elements that are subject to aging and reduce the system reliability. Furthermore, MCs provide bidirectional power flow, nearly sinusoidal input and output waveforms and controllable input power factor. Therefore, MCs have received considerable attention as a good alternative to Voltage-source Inverter (VSI) topology. The development of MCs started when Alesina and Venturini (1981) proposed the basic principles of operation in the early 1980's. Afterwards, the research in this field continued in two directions. On the one hand, there was the need of reliable bidirectional switches on the other hand, the initial modulation strategy was abandoned in favor of more modern solutions allowing higher voltage transfer ratio and better current quality. In the original, Alesina and Venturini (1981)'s theory, the voltage transfer ratio was limited to 0.5 but it was shown later that by means of 3rd harmonic injection techniques, the maximum voltage transfer ratio could be increased up to 0.866, a value which represents an intrinsic limitation of 3 phase MCs with balanced supply voltages (Alesina and Venturini, 1989).

A new intuitive approach towards the control of matrix converters often defined Indirect method was presented by Ziogas *et al.* (1986). According to this method, the MC is described as a virtual 2 stage system, namely a 3 phase rectifier and a 3 phase inverter connected together through a fictitious dc-link. The indirect approach has mainly the merit of applying the well-established Space Vector Modulation (SVM) for VSI-MCs, although initially proposed only for the control of the output voltage (Huber and Borojevic, 1989). The SVM was successively developed in order to achieve the full control of the input power factor to fully utilize the input voltages and to improve the modulation performance (Huber and Borojevic, 1995; Casadei *et al.*, 1993). A general solution of the modulation problem for MCs was presented by Casadei *et al.* (2002) based on the concept of duty-cycle space vector that allows an immediate comprehension of all the degrees of freedom that affect the modulation strategies. In this study, proposes the matrix converter act as a frequency regulator for utility. Because frequency directly affect the performance and operation of AC machines and equipments. The basic structure of matrix converter is shown in Fig. 1.

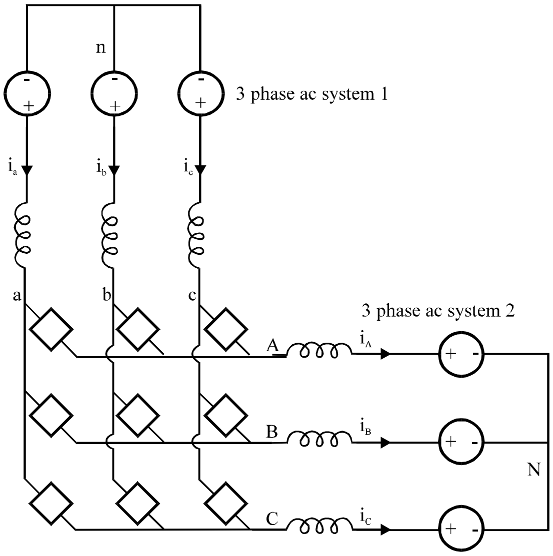

Fig. 1: Basic structure of matrix converter

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IMPORTANCE OF FREQUENCY QUALITY

Power quality is the set of limits or conditions of electrical properties that allows electrical devices to function in their planned manner without loss of performance (Monedero *et al.*, 2007). Without proper power, an electrical utility or load may malfunction, fail permanently or not operate at well. The main power quality problems are voltage sag, voltages well, voltage harmonics and current harmonics and supply frequency variations (Mishra *et al.*, 2008). As mentioned before power quality issues are mitigated by using unified power quality conditioner except supply frequency variation. Supply frequency is an important issue in power quality. In order to characterize, the power system frequency under normal operating condition the following indices are used:

$$\Delta f = f - f_r \tag{1}$$

Where:

f_r = Rated frequency (50 or 60) Hz
f = Real frequency

The relative frequency deviation:

$$\varepsilon f(\%) = f - \frac{f_r}{f_r} * 100 \tag{2}$$

The integral deviation during the delay required to ensure appropriate of clock synchronized to the electrical network frequency:

$$I_f = \int_0^{24} \Delta f \cdot dt \tag{3}$$

According to the standard En 50160/2006 rated frequency of supply voltage is 50 Hz. Under normal operating condition, the mean value of the fundamental frequency measured over loss stay within the range; 50 Hz±1%, i.e., 49.5-50.5 Hz for 99.5% of the year, 50 Hz±4%, i.e., 47-52 Hz for 100% of the time. But normally, the power frequency may not be exactly 50 Hz within the time interval. The fundamental frequency output is the ratio of the number of integer cycle counted clearing 10 sec time interval divided by the cumulative value of the integer value. The steps taken to maintain the frequency with in required limits render deviation from the normalized value. In this way, an analysis is of the influence of frequency variation on the final customer is only for a reduced interval about ±3 Hz of the rated value and for rather short period (Sarri, 1991). Within the reduced variation field (40%), a considerable number of static customers are not affected by the system variation (rectifier, resistance, ovens, electric arc, etc.) but 60% of the consumers (fans, motors, etc.) are affected by the frequency variations. The change in supply frequency hardly occurs in large distribution systems based on ground faults. If there are some major disturbances or very heavy load fluctuating continuously then the frequency variation will be occur (Golkar, 2004). But large frequency variations are possible on electrical systems used on heavy sudden load and emergency supply systems for factories and hospitals. Such large frequency variations are possible on low power systems where diesel engines and gas turbines are used as prime movers.

Effects of change in supply frequency on torque and speed: The asynchronous and synchronous driving motors connected to the supply network used extendedly in individual acceleration have the power frequency changes. Depending on the mechanical characteristic, the speed of the motor depends on the supply frequency (Blodt *et al.*, 2008).

The speed of an asynchronous motor or synchronous motor unlimited drags to the electric power supply variation is proportional to the applied voltage frequency. The frequency variation leads to the necessary modification of the process production time throughout the supply with a reduced frequency, depressing the supply frequency capacitive circuit, transformer and relay coil are affected. The torque is related to the motor output power and the rotor speed. AC motor characteristic requires the applied voltage to be proportionally adjusted whenever the frequency is changed the motor changes to deliver the rated torque. For a case if a motor is designed to operate at 450 V at 60 Hz, the applied voltage must be reduced to 230 V when the frequency is reduced to 30 Hz. Thus, the ratio of Volts per Hertz must be regulated to a constant value (450/60 = 7.67 V Hz^{-1} in this case). For optimum performance, voltage adjustment may be needed especially at low speeds. But a constant Volts per Hz is the general formula. This ratio can be changed in order to change the torque delivered by the motor:

$$T_{load} = \frac{F_m}{\omega_m} \text{NM} \tag{4}$$

$$\omega_m = \frac{2\pi n_m}{60} \frac{\text{rad}}{\text{sec}} \tag{5}$$

Lifetime of the bearings is also limiting the maximum speed of the motor. It is recommended to consult the motor manufacturer if >150% speed is required by the application. The synchronous speed of an induction motor is based on the supply frequency and the number of poles in the motor winding can be expressed as:

$$\omega = 2 * \frac{60f}{n} \tag{6}$$

Where:
ω = Pump shaft rotational speed (rev/min, rpm)
f = Frequency (Hz, cycles/sec)
n = No. of poles

Effects of change in supply frequency on horse power and torque: The frequency also involved in horsepower rating of the motor known as this formula:

$$\text{HP} = \frac{\text{rpm} \cdot \tau(\text{torque})}{5252\ (\text{constant})} \tag{7}$$

As mentioned previous, the relation between the speed and its frequency of the motor is based on the expression N = 120 f/P. From this expression, it is prove that the speed of the motor is directly proportional to the supply frequency. So, any decrease or increase in the frequency will affect the speed of the motor (Barnsley, 1990). Suppose when a 50 Hz motor is made to run on 60 Hz supply in general practices, several countries have all house-hold items and equipments rated for 50 Hz power supply. So when such small domestic devices are connected to a 60 Hz power supply, they cause a severe problem. That is:

$$\left[\frac{(60\text{ Hz} - 50\text{ Hz})}{50\text{ Hz}}\right] * 100 = 20\%$$

Thus, all such equipments will run 20% faster than their normal rated speed. This is not safety for the equipment as the insulations may be rated for lesser capacity and windings will burn-out. To run safely manner should add a reduction gear or an expensive 50 Hz source. Also, this 50 Hz motor will operate perfectly on a 60 Hz supply provided its supply voltage is stepped-up as 60/50 Hz = 6/5*100 = 120%. Suppose, a 60 Hz motor is connected to 50 Hz supply. It is same as the above but instead of stepping-up the supply voltage, it is necessary to step-down the supply voltage. The 50/60 Hz = 5/6* 100 = 80%. The speed of an induction motor is given as N = 120 f/p (1-S). So, obviously the speed of an induction motor can be controlled by varying any of three factors namely supply frequency (f), number of Pole (P) or Slip (S). Motor torque is directly propotional to supply frequency (Adeel *et al*., 2009):

Motor torque = flux density*I

Flux density = K*(V/Hz)

Where:
K = Motor constant
V = Voltage
Hz = Frequency

$$\text{Motor torque} = \left(K * \frac{V}{\text{Hz}}\right) \tag{8}$$

Effects of change in supply frequency on transformer output: A transformer is a static piece of apparatus by means of which electric power in one circuit is transformed into electric power of same frequency in another circuit. The rms value of EMF induced in the transformer depends on the supply frequency. Induced EMF in the primary winding:

$$E_1 = 4.44\ f\ N_1 B_m A \tag{9}$$

Similarly, the rms value EMF induced in the transformer secondary winding depends on the supply frequency:

$$E_2 = 4.44\ f\ N_2 B_m A \tag{10}$$

where, N_1 and N_2 are the number of turns in primary and secondary winding.

PROPOSED FREQUENCY REGULATOR

Structure of matrix converter: Basically, a Matrix Converter (MC) is composed by nine bidirectional switches as shown in Fig. 1 where each dot of the grid represents a connection between the output and the input terminals. The converter is usually fed at the input side by a three phase voltage source and it is connected to an inductive load at the output side. The schematic circuit of a matrix converter feeding a passive load is shown in Fig. 2.

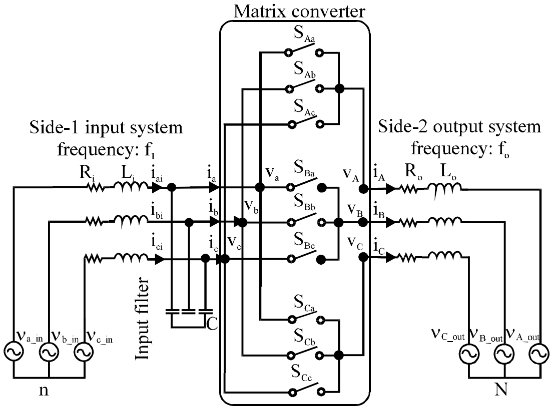

Fig. 2: Basic structure of matrix converter

The system is composed by the voltage supply, an L-C input filter, the MC and a load impedance. The MC requires bidirectional switches with the capability to block the voltage and to conduct the current in both directions.

There are two main topologies for bi-directional switches, namely the common emitter anti-parallel IGBT configuration and the common collector anti-parallel IGBT configuration. The common emitter arrangement is shown in Fig. 2. As can be seen, two IGBTs are connected with two diodes in an anti-parallel configuration. The diodes provide the reverse blocking capability. The complete connection scheme of the common emitter arrangement is shown. The main advantage of this solution is that the two IGBTs can be driven with respect to the same point, i.e., the same common emitter that can be considered as a local ground for the bidirectional switch. On the other hand, each bidirectional switch requires an insulated power supply in order to ensure a correct operation. Hence, a total of nine insulated power supply is needed. The power supplies must be insulated because as a bidirectional switch is turned on, the common emitter assumes the potential of an input phase. Therefore, it is not possible for all the bidirectional switches to be driven with respect to the same common point.

Frequency regulator system: The matrix converter consists of nine bi-directional switches arranged in three groups, each being associated with an output line. This bidirectional switches arrangement connects any of the input lines to any of the output lines. A matrix with elements S_{ij}, representing the state of each bidirectional switch (on = 1, off = 0) can be used to represent the matrix output voltages (v_u, v_v, v_w) as function of inverters. Figure 3 shows the control system of the frequency regulator. The matrix converter is controlled by space vector modulation. The modulation reference voltage is used to control the regulation of output frequency. The supply frequency $V_{f(abc)}$ is sensed by the frequency counter. It is compared with the reference frequency $V_{f(ref)}$ and extract the error value. The compensated value is produced by the PI controller and compensated frequency is fed to the Phase Locked Loop (PLL). When the supply frequency is varied beyond the power quality limit, the frequency controlling system (matrix converter) changes the required PLL frequency from PI controller.

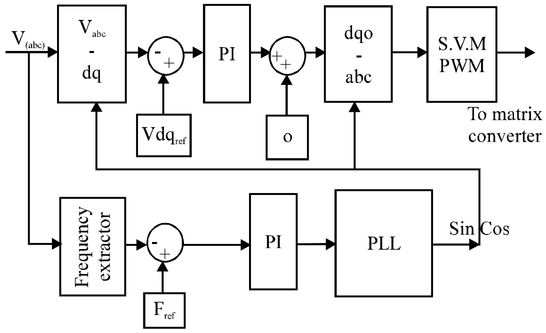

Fig. 3: Control system of the frequency regulator block

SIMULATION RESULTS

The proposed system, simulation result is simulated by the Matlab software. The simulation of the matrix converter operation without input capacitor is shown (Fig. 4). Here, the line voltage is 230 V; the supply current is 120 Amperes. In this simulation, the input current wave shape is non-sinusoidal and it contains harmonics. The simulation time starts from 0-0.08 sec. Consider the simulation time is from 0-0.025 sec as the one cycle of the current wave form. Here, the wave shape of this current is non sinusoidal and it contains harmonics. Figure 4 shows the input voltage is harmonic free. The input current wave form of the matrix converter. Figure 5 shows the load voltage of the matrix converter output and the load current applied to the load. Here, the load current is resistive load. Figure 6 shows the system response when the supply frequency increases above the power quality limit.

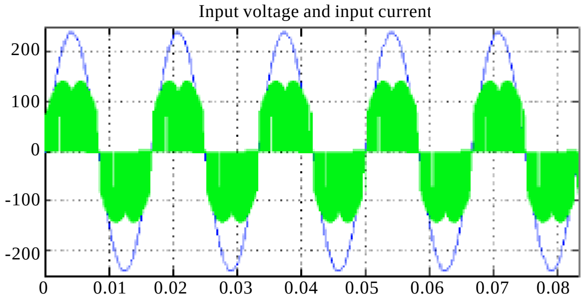

Fig. 4: System voltage (V_s) and source current (I_s)

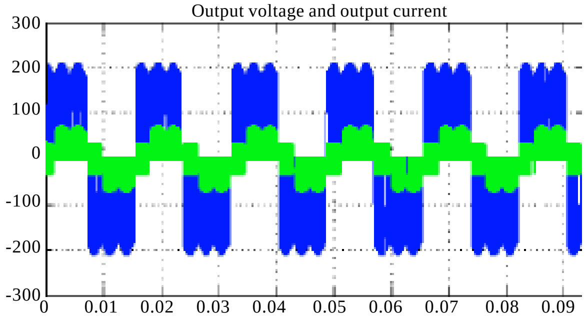

Fig. 5: Load voltage (V_L) and load current (I_L)

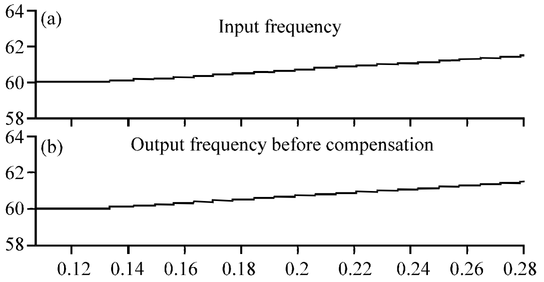

Fig. 6: a) Supply frequency rise above the power quality limit and b) output load frequency without compensation

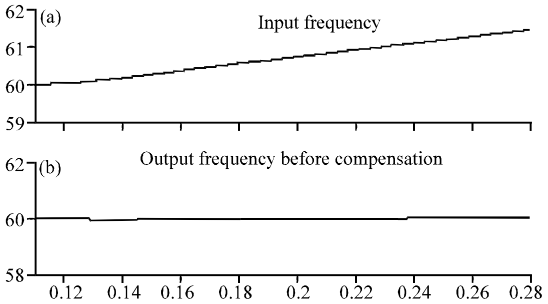

Fig. 7: a) Supply frequency rise above the power quality limit and b) load frequency with proposed compensation

It is shown in Fig. 6b that as the frequency increases (from 60-62 Hz), the input supply frequency varies at the same time, the output frequency also varies. Frequency variation starts from 0-0.14 sec linearly as shown in Fig. 5b. Figure 7a shows the system response.

The supply frequency is increased above the power quality limits. It can be seen that the frequency increases from 60-62 Hz. The proposed system regulates the load frequency to a constant level. The frequency variations starts from 0.14-0.28 sec linearly as shown in Fig. 7a. From Fig. 7b, it can be inferred that the output frequency is almost constant even when the supply varies.

CONCLUSION

This study has presented a model of custom power equipment, namely frequency regulator. The study illustrates the operation and control of matrix converter based frequency regulator. This device is connected in between source and load. When an unbalanced, frequency sensitive load is supplied with this equipment it will regulate the supply frequency. The main aim of this device is used to regulate the supply frequency at the load terminal. The proposed method can regulate the supply frequency efficiently using matrix converter. The simulation results showed that the proposed system has the ability to control the power frequency variation within the power quality limits.

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