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Harmonic Comparison of Three Phase Direct Matrix Converter for Reactive Load with Balance and Unbalance Supply Voltage

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ABSTRACT

This paper presents harmonic analysis of matrix converter using different control technique for balance and Unbalance three phase input voltage of reactive load. Since Matrix converter is subject to affected either by external disturbance or by load conditions. Due to this the supply voltage becomes unbalance. This cause improper switching of matrix converter results higher harmonics. This harmonics are harmful to the quality of the output power. The switching sequence of the matrix converter is controlled by vector control method. Different control technique is proposed in this paper to get optimized result with reduced harmonic for unbalanced and balance input voltage using PID, Fractional Order PID (PIλDδ) controller (FOPID), Particle Swarm Optimization (PSO) FOPID. PID control technique result are compared with other optimization technique for best optimum output. The FOPID controller is used to compensates the current and also improvise the quality of energy by reducing the harmonic content. The simulations and hardware results will be presented and interpreted. The effectivess of the proposed system is proven with the results is shown in this paper which produce a better steady state lesser transient rather than the conventional PID method

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1. INTRODUCTION

Recent decades the attention towards the matrix converter engrossed by many researchers. Since, matrix converter have many advantages compared to the other converters like AC voltage Controller, Cyclo-converters and other inverter circuits. The matrix converter affords more advantage such as bi-directional power flow, modifiable power factor, Sinusoidal output current and voltage, higher stability and a very important character of the direct matrix converter it does not use any capacitor between the input and output power stages.

The Matrix Converter is constructed from bidirectional power switch arranged in an array of m x n. There are three m and n switches are arranged in such a way to enable three input line connected to output phase irrespective of time. The PWMs are generated for 3^3 =27 switching combination excluding the non-switching state. Suitable control technique is provided for converter to achieve sinusoidal output. Since matrix converter is well known by ac to ac conversion.

The load side of Direct Matrix converter (DMC) shown in Figure.1 can be easily affected by unbalanced input voltage due to nonexistence of capacitance between the load and supply. An undesirable harmonics can be generated on the load current due to distorted input voltages. If matrix converter is exposed to the non-sinusoidal current and harmonic, the performance output of matrix converter will be depreciated.If this disparaging effect can be eliminated using suitable technique the reputation of the DMC can beincreased further.

Many control techniques are proposed for matrix converter to get optimal results. Space vector modulation (SVM) produces the better result compare to other methods due to vector control method [1] [2] [3]. Since the voltage in the three phase rotate in vector notation. The performance of the direct matrix converter is influenced by input and output under balance and unbalanced conditions. In this paper the harmonic of different control methods are evaluated and a new control technique is proposed for the best result. Initially the Direct matrix converter (DMC) has been discussed with two control technique PID and FOPID. Later the best method is selected for optimization technique to reduce the harmonics further. In the first method, the vector of input current is kept in phase with vector of input voltage. Whereas in the next method the harmonic content of the input can be reduced by controlling input current displacement angle. In the Proposed control strategies minimizing the output current distortion and eradicating the influence of symmetric supply voltage is achieved by reducing the zero vectors.

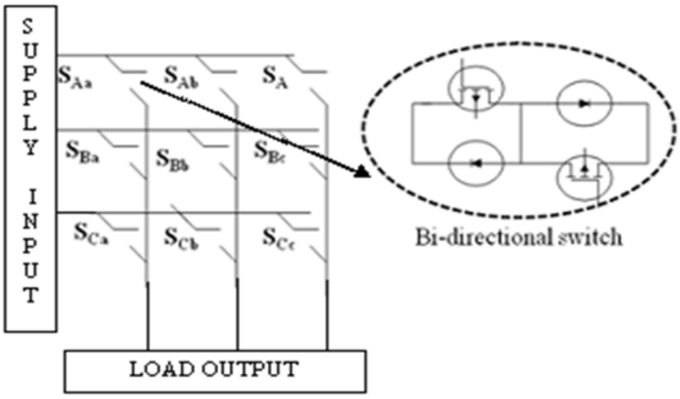

Figure 1. Simple Matrix Converter Topology

In order to achieve the above result a novel compensation technique has been proposed to eradicate the detrimental effects of the imprecise input voltages for matrix converter controlled with SVM modulation method using FOPID controller. Under closed loop control of DMC this technique produce good performance for different load current. In the proposed method a suitable control technique is used to diminish the harmonics but also to maintain the power factor nearby unity. Theusefulness of the proposed method is proven using few simulation and hardware results presented for both PID and FOPID.

2. CONTROL TECHNIQUE

Latest year there are many research proposed many method on DMC. Different control techniques was followed both in vector and scalar methods. Many papers proposed on scalar control technique to solve the impact on unbalanced supply voltage [4] [5] [6]. Since vector control method is proposed in this paper due to the advantage discussed earlier.In this paper the focus is on harmonics control of matrix converter, initially the basic PID controller is chosen, later a slight modified version of PID is used named FOPID. The FOPID controller is further tuned using PSO. In the following sub chapter the details of each technique was discussed and corresponding results also plotted for the proof.

2.1. PID Control Technique

Most of the academic researchers, industrial researchers and industrial application are broadly using the PID control technique due its simplicity, superior performance like minimal overshoot, shorter settling time for slower systems. The main requirements for any closed loop control system was rejection of the disturbance and exclusion of noise to achieve the sustained the stability and robustness. Tuning of PID controller is most vital issue in industrial and plant controllers. Due to ability of tuning the parameters like proportional, integral and derivative are physically or self-tune mechanically.

In PID Controlled Direct Matrix Converter technique the Control variables of the PID controller select the relevant switching sequence out of 27 combination [7]. The 27 switching combination is resolute by SVM algorithm. Constant and controlled current and voltage can be achieved by properly selecting the PID tuning parameters [7]. The harmonics of different control technique is compared for the fixed load. The value of PID tuning parameters such as Kp, Ki and Kd are chosen by iterations method. For each iteration the above parameters are changed still to get required output. Based on the error output and harmonics, the tuning parameters are reformed. Power factor is an important trait during the study of the matrix converter. The simulation result in Figure 2 shows the voltage and load current almost in phase each other. Since the voltage and current magnitude are chosen very low value. It is evident in further analysis the Power factor for direct matrix will reach nearby unity.

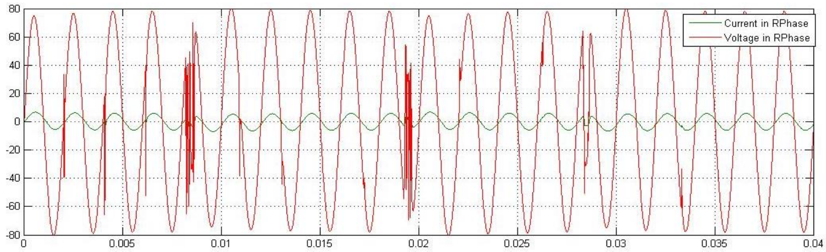

Figure 2. Simulation result of Voltage and Current for single phase

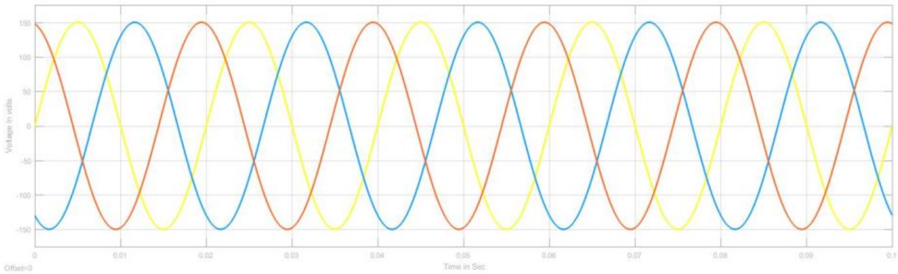

Figure 3. Balance Three Phase Source voltage

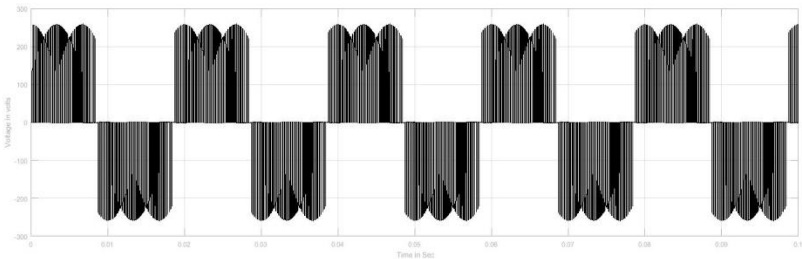

Figure 4.BalanceThree Phase Load voltage

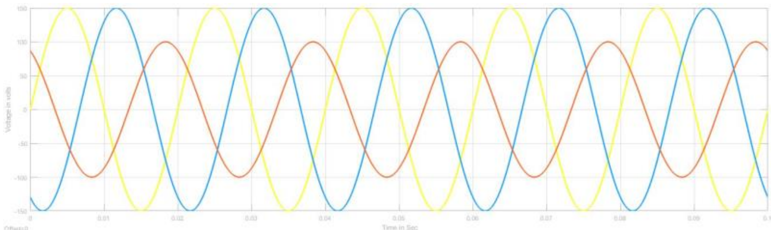

Figure 5. UnBalance Three Phase Source Voltage

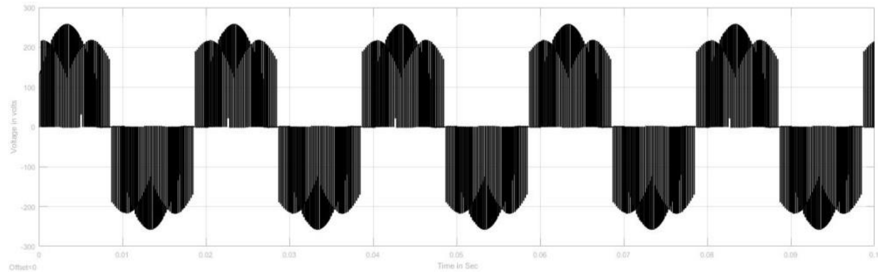

Figure 6. UnBalance Three Phase Load voltage

The simulation results of PID control shows some significant improvement of load current. With further turning the load current is controlled smoothly and maintained constant. Since, the analysis is deals with both balance supply and load voltage shown in Figure. 3 and Figure 4 respecitively. Similarly the Unbalance supply and load voltage shown in Figure.5 and Figure.6 respectively. The percentage of harmonics is about 61% due to unbalanced supply voltage shown in Figure 7 and the percentage of the harmonics reduced in case of balanced supply voltage shown in Figure 8. Initially the Percentage of Harmonic is almost 50% and above in case of balance supply voltage. But later as the controller makes the load current to steady state the harmonics start reducing. The quality and robustness of the controller as to be improvised inorder to achieve better performance and lesser or lower harmonic distoration. Therefore, the conventional PID controller can be replaced with a new or improved PID controller. Fractional order PID controller with fractional order of I and D is used in the proposed system to overcome the above problem. In recent years, in the area of modeling and controlling fractional calculus has been plays vital role. The FOPID has two additional parameters like fractional integration λ and the order of fractional derivative δ, along with proportional, integral and derivative parameters (Kp, Ki, and Kd) in PID Controller. Therefore, the FOPID has five parameters for flexible control.

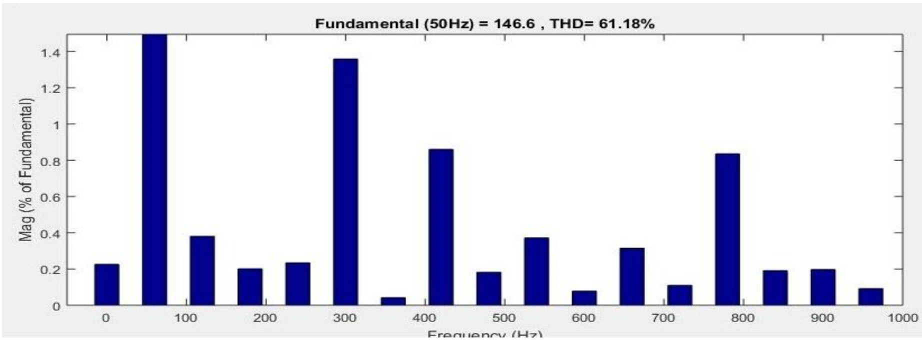

Figure 7. Harmonic Analysis using PID Controller for Unbalance supply voltage

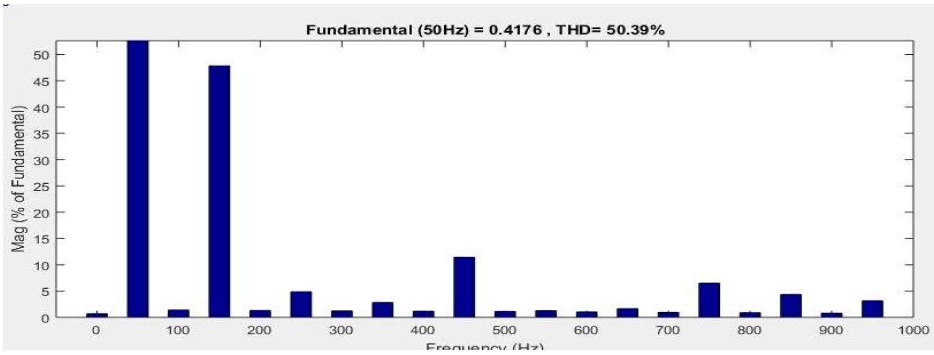

Figure 8. Harmonic Analysis using PID Controller for Balance supply voltage

2.2. Fractional Order PID Control Technique

Podlubny [8] was proposed a new control technique named Fractional Order Proportional Integral Control (FOPID). Since, this control technique affords extra degrees of freedom for more dynamic performance compared with earlier method of PID [9]. Since FOPID produce more robustness of the system compared to the Conventional PID Controller FOPID algorithm gives better result than previous [10]. Recent years the FOPID controller has received attention of man researchers. The FOPID controller Eq. (1) is shown below.

$$K(\mathrm{S}) = \mathrm{K}_P + \frac{K_I}{S^{\lambda}} + K_D S^{\mu} \quad (1)$$

Where Kp, KI, and Kd, λ and μ are proportional, integral, and derivative gain, orders of integral and derivative respectively.

In the above discussions the harmonics obtained by using conventional PID controller was shown. It is evident that harmonics obtained by using above method greater than the tangible. The same approach was carried out using different control technique. The order of the PID parameter changed and named as FOPID technique. The best value of FOPID parameter are determined for optimal outcomes. Using FOPID technique the control parameters are tuned and produce the best result. The control parameters are chosen for the best switching sequence in order to get controlled current. The switching sequence of the matrix converter is previously determined by scalar and vector control method. The switching sequence is controlled by the SVM technique is optimized FOPID. Based on the nature of the load and supply voltage the load current is controlled. Figure 9 show the load current obtained when the supply voltage is under balance condition. The tuning parameter of the FOPID controller is determined by iteration method.

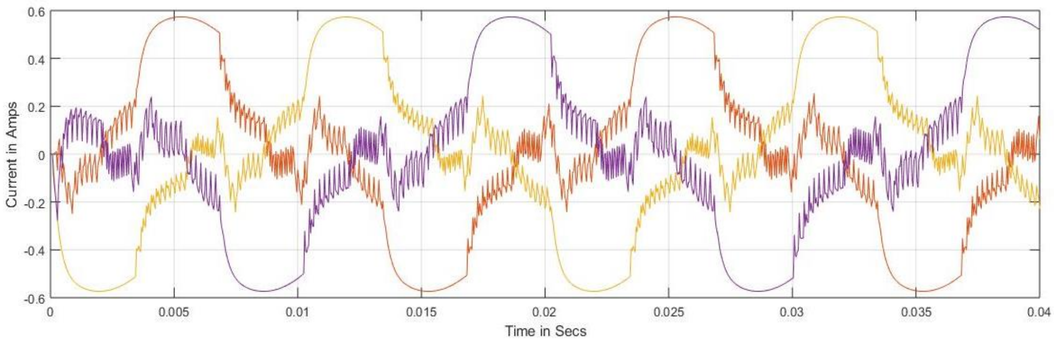

Figure 9. Three phase current of Direct Matrix Converter using FOPID Controller

In the above PID method the harmonics obtained was initially higher, later it start diminished. But if the harmonics level is greater it leads to poor quality of power. Since the aim of the any controller is to reduce the harmonic to acceptable limit to improvise the power quality [11] [12]. In Figure.10 show variation of the harmonics level from the initial state due to FOPID controller for unbalance supply voltage a Figure. 11 show the variation harmonics due to balance supply voltage. It is proven from the analysis the FOPID controller have better roboustness compare to PID controller. Moreover the harmonics obtained from both balance and unbalance voltage is not much deviations. It indicate that FOPID control technique better results both in the form of load current and reduction of Harmonics.

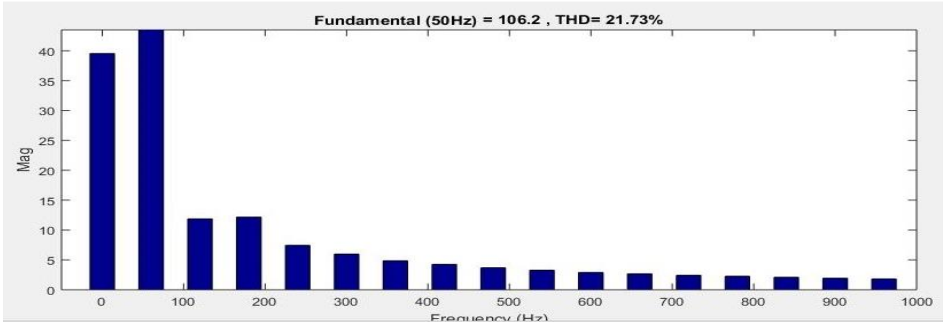

Figure 10. Harmonic Analysis for Unbalance supply voltage using FOPID (Trial and End)

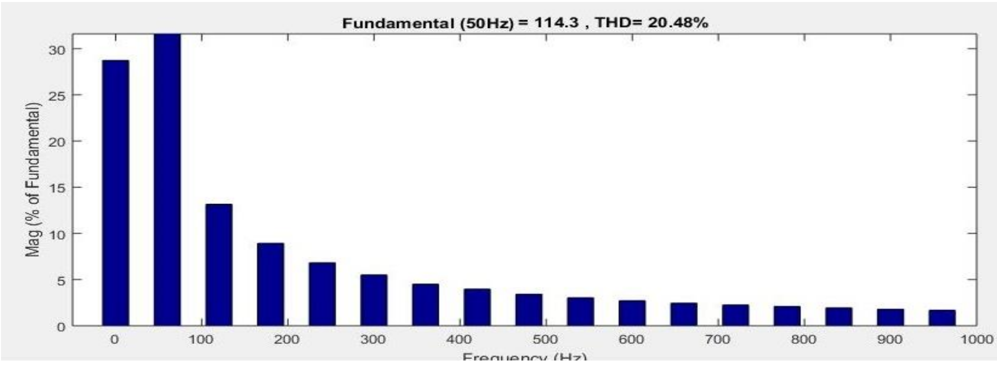

Figure 11. Harmonic Analysis for Balance supply voltage using FOPID (Trial and End)

2.3. Particle Swarm Optimization Control Technique

In the above methods both in PID and FOPID control technique the control parameters values was choosen by iteration method. This results the harmonic caused by both of the method is not tangiable limit. Therefore a better method is identified to find best value of FOPID control parameters. Since there are many Optimization techniques was used by lot of researcher. PSO is found to be one of the popular and best method to tune the PID parameters. Computational intelligence technique find more optimal output for the complicated systems more quickly and accurately. The method followed by the optimization technique to get optimized result was computational intelligence.Computational intelligence is nothing but combination of erudition, adaptation and evolution to produce a set of sequence to implement [13].

Particle swarm optimization (PSO) is a kind of computational based swarm intelligence technique [14]. This process is based on replication group of animal's communication and its behaviors such as fish schooling and bird flocking. It bear a resemblance to the approach of finding the food by teamwork and antagonism among the whole population. A swarm comprises of distinct particles, each unknown parameter to be optimized is located in different position. The population of the swarm is adjusted arbitraryly. In a PSO system, particles flutter around the multi-dimensional hunt space, modifying the location harmonizing to its own acquaintance and the knowledge of its adjacent particle [14] [15]. The objective is to find the best solution for the problem occurred in the previous iteration with purpose for finding the better result in the sequence of the process which finally covers a particular solution either least or maximum. According to the pre-defined fitness value the enactment of every particle is measured, which is difficult to solve.

PSO Algorithm consists of 'n' number of particles and every particle enter into 'W' dimensional space. Based on three principle each particle change its position

- The inertia of the particle or elements keep constant.
- The state of the particle is altered based on most optimized situation.
- The state of the particle is altered based on most optimized position of swarm.

The location of every particles will be reorganized to new position. The reorganized new position is due to the most optimized position of its previous positions. As the positon of the particle is keep on altering based on most optimized position, the velocity of the particle also changes proportionality. The new updated position of every particle and corresponding velocity can be calculated by two Eq. (2) and (3) respectively.

$$v_{iw}^{k+1} = M.v_{iw}^{k} + C_1.\text{rand}([\text{Pbest}_{\text{iw}} - x_{iw}^{k}]) + C_1.\text{rand}([\text{gbest}_{\text{iw}} - x_{iw}^{k}]) \quad (2)$$

$$x_{iw}^{k+1} = x_{iw}^{k} + v_{iw}^{k+1} \quad (3)$$

Table1. PSO Selection Parameter

PSO PARAMETER	Values
Population Size	5
Number of iteration	5
Velocity Constant C1	1.2
Velocity Constant C2	0.12
Inertia M	0.9
Dimension W	5

Where V and X are the velocity and position of the every particle; M is the inertial weight constant; the regulation constants are namely C1 and C2;rand is random number generation between 0 and 1 and finally Pbest and gbest are the position of every particle. Here Pbest is the position of the particle in best positon and gbest is the global best position of the particle in the entire swarm, i=1,2,3,….,n; where n is a number of particles in swarm. w=1,2,3,….,W; where W is a number of dimensions of the particle (number of variables that optimize the fitness function.

It is clear from the above discussion, PSO technique achieve the objective in the best way. Since in the proposed method FOPID controller is used to control the DMC. The parameter of FOPID was tuned using PSO technique. It is evident form the Figure.12 due to unbalance supply voltage the harmonics is almost reduced 5 times of basic PID controller and 2 times of FOPID controller using manual tuning. Figure.13 also proves if the supply voltage is in balanced condition, the harmonics can be reduce less than prescribed limit.

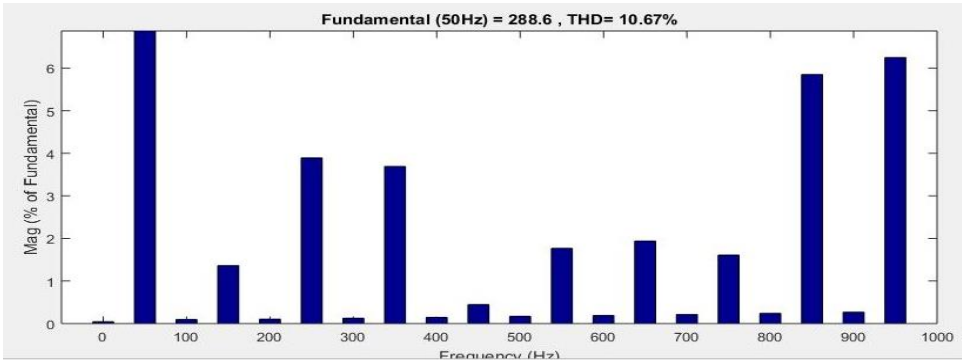

Figure 12. Harmonic Analysis for Unbalance supply voltage using PSO tuned FOPID

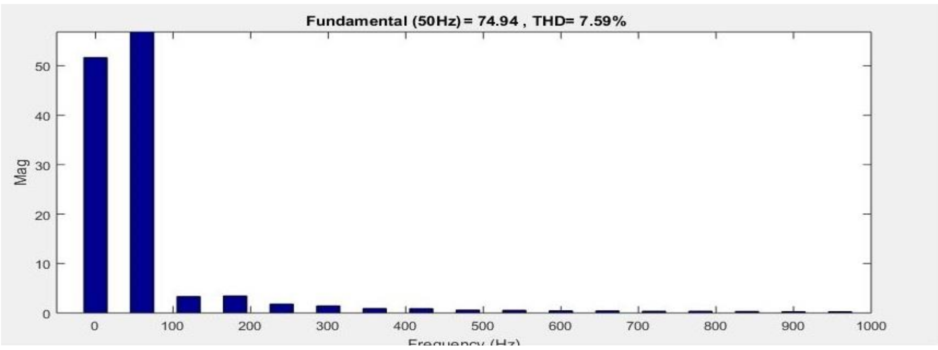

Figure 13. Harmonic Analysis for Balance supply voltage using PSO tuned FOPID

Table 1. Shows various tuning parameter of PSO for FOPID algorithm. The assumption made in the above table 1. is initial assumption. In order achieve the much better result the PSO parameters can be tuned with different values [16]. Since using the above value the required output is reached and the results are obtained.

Table 2. Comparision of other Control methods

Control Technic	Feasibility	Disadvantage	Reference
PI	• Controlling can be done easily. Therefore the system can achieve linearity	Harmonic generation is subjected to load condition	[17[18]
Hybrid PSO Control	• Good Torque response • Lower startup current	GA learning technique quite complex	[19]
PSO-PI controller.	• Unidirectional Power flow • Reduced distoration • Sinousoidal output	More switches due to indirect matrix converter	[20]
SVM	• Lowest rms three phase rms value • Reduced harmonic content	Two methods used to control the harmonics	[21]

In past decade many researcher proposed different method of control technique for matrix converter to obtained best result. Table.2.shows some few control method proposed by the researcher for matrix converter their findings and issue of the control technique. In the proposed technique the converter uses very less number of switches and single control technique with higher voltage gain. The issues caused in the previous methods of matrix converter can be resolved in the proposed method. The results obtained and shows in different graphs proves satisfactory result.

3. HARDWARE IMPLEMENTATION OF PSO TUNED FRACTIONAL ORDER PID CONTROL

The FOPID controller parameter such as Kp, Ki , Kd, fractional integration λ and the order of fractional derivative δ optimal values are determined by using PSO technique. The purpose of the PSO algorithm is to tune the above parameter for the all possible values to reach the least error. The Particles of the PSO technique is consider as the controller parameter of the FOPID. Therefore, each time the FOPID controller changes to the finestposition to meet the stability. Certain parameters need to be redefined so as avoid the escaping of local variables from the global variable due to the maximum velocity of the particles.

The FOPID controller ensures the parameter, so that the output result come across the stable system. The parameters are so selected to accomplish the global minimization of error constant. Initializing the values PSO algorithm such as C1, C2 and velocity is shown Table.1.Since the results obtained for FOPID shows better than the PID controller. The controller and the hardware is designed for the proposed technique. The Figure.14 shows the full hardware setup of the matrix converter. The load used for the FOPID technique is Resistive and Inductive shown in Figure 15.

Figure 14. Direct Matrix Controller Hardware setup

Figure 15. Resistive and Inductive Load Used for Testing The Results

The values of L and C filter parameters on the load side is determined experimentally 48 mH and 0.01µF respectively using the relation between the output voltage and the output current for R-L load[22]. The simulation results of matrix converter are interpreted using PSO tuned FOPID R-L load. The proposed model has been implemented both in simulation and hardware. Subsequently, the complete results of comprising only the load side parameters using R-L load with R and L values as 398Ω and 48 mH respectively. It can be observed that for varying climatic condition, and due to variable climatic condition [23] the proposed design is capable of delivering high quality and low distortion power efficiently to the loads at unity power factor.

The same load is tested for both simulation and hardware. The hardware result shown in Figure 16 is tested for 15V Phase to neutral and with same load type. The load current is tested using the same voltage show in Figure 17. The load current obtained steady state as the controller prolongs control the matrix converter [24]-[25].

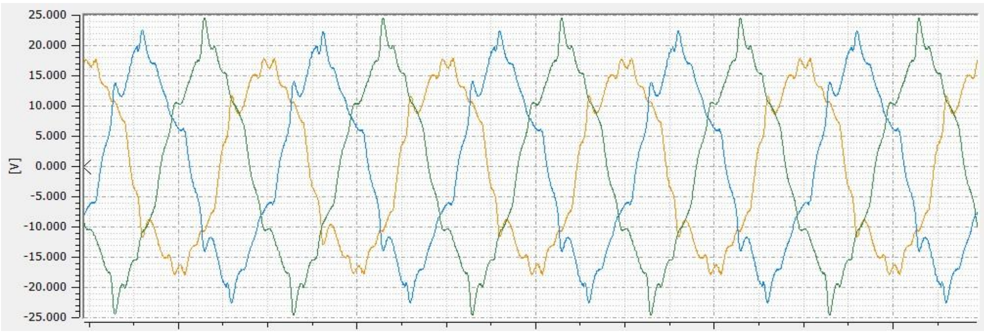

Figure 16. Hardware result of Three Phase unbalanced Voltage using FOPID method

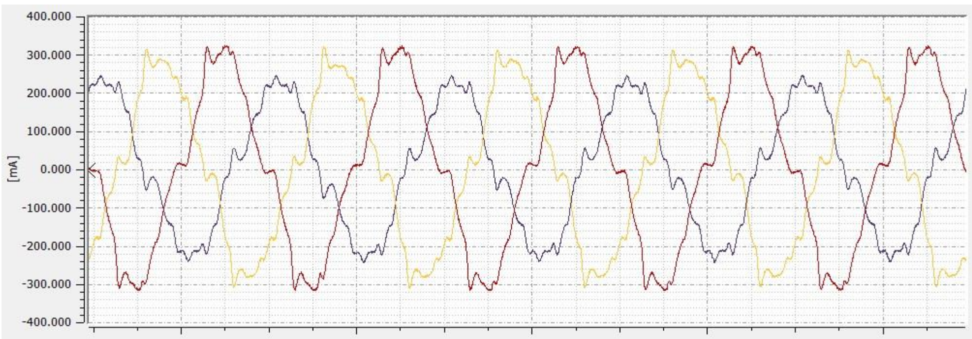

Figure 17. Hardware result of Three Phase controlled current using FOPID method

As discussed in the simulation results the harmonic generated initially more. When the controller starts controlling the switching sequence [26] the converter will able to produce a steady state output. Moreover as discussed earlier the power factor obtained by the proposed method is almost unity [27]. In Figure 16 the First and third order harmonics are shows in Figure.18 the variation of values in terms of percentage. During the initial switching period as the current not reaches the steady state and switches triggered randomly. This cause the initial harmonics is high, as the current is controlled by the converter the harmonic suddenly comes to lesser percentage. For a proof of result it is shown in Figure 18. The third harmonics is almost less than 10%. Further as the current continuous to maintain steady state the harmonics reduces below 5%.

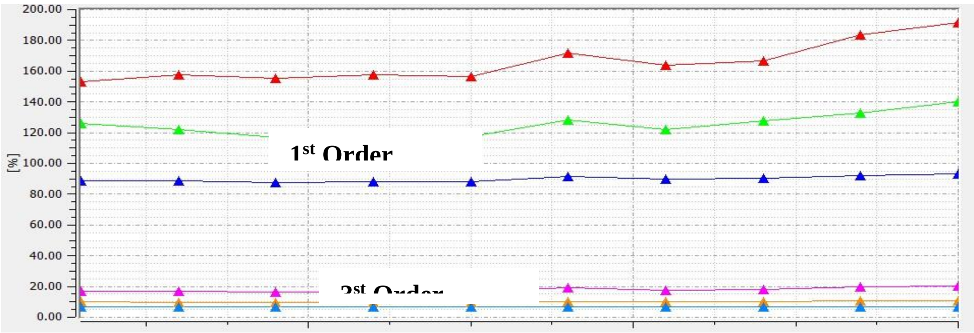

Figure 18. Harmonic analysis of FOPID controller using Hardware result

The Total harmonic distortion waveform of the MC current is almost a satisfactory solution. Corresponding results are also presented, thereby the MC substantiates its capability of providing high quality and low distortion power for wind energy with uninterrupted power supply.

4. CONCLUSION

From the above discussion, the proposed PSO based FOPID controller gives a better robustness and acceptable result for the given load conditions. In this paper, a swarm intelligemce technique was carried out to enhancing the competence of FOPID to overcome the disadvantage occurring in conventional PID and FOPID controller, Since the FOPID choose the best switching sequence from the SVM technique. Fractional calculus affords different and higher performance for FOPID controllers which result in enhanced output. The variation of Harmonics i.e from 61.18 % to 7.59% shows the significant changes from the initial value to final value due to change of controller and controller tuning method. Moreover, the harmonics caused by both balanced and unbalanced supply voltage is improved ample because of the tuning technique of the FOPID controller.

In order to lessen the difficulty of the designer for designing the controller, PSO gives multiple advantages to function with a less number of design approaches applied for controller.The THD result of direct matrix converter proves ominously low harmonic contents at their output even for various reactive load condition of different energy systems. The above hardware results proves that the harmonic content caused for reactive load was reduced much for different conditions. In order to achieve higher efficiency for various load, the controller is tuned precisely. Therefore the controller parameters are increased to achieve the better result. The percentage of harmonics caused due to PID controller and FOPID is reduced in PSO. Thus the PSO produce a satisfactory results in form of both simulation and hardware for controlling the load current and harmonics. Moreover, by using this technique the power factor can be maintained near unity and voltage ratio also appropriate to 1.

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