PSO Supported Dual Matrix Converter for Doubly fed Induction Generated Driven by Variable Speed Wind Turbine System

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Abstract- The growth of wind energy conversion technology has become one of the most important and promising sources of renewable energy. The evolution of wind farms is very recognized in this new trend. This paper concentrates mainly on the performance of the variable speed wind turbine system using the Doubly Fed Induction Generator (DGIF) controlled by Matrix Converter (MC). The DFIG fed by a MC for the best performance of variable wind energy systems. In this paper the Dual MC Drive system was introduced, one MC is placed to control the DFIG and the other kept to control Induction Motor (IM) load. The classic Direct Torque control (DTC) control technique applied on DFIG for getting fixed output voltage. The simple DTC control implemented for the best performance. The Particle Swarm Optimization (PSO) based switching strategy significantly reduces the harmonic content in the MC. In this study, PSO, Mutated PSO (MPSO) techniques were implemented on MC. The proposed test system was discussed and implemented in both software (Matlab/Simulink) and hardware. The DFIG based variable wind energy system with MC and IM controlled MC were implemented in software. With the hardware prototype of the system with IM controlled MC was tested, for the hardware prototype constant wind supply has been assumed. This proposed PSO based switching control strongly recommend for MC fed DFIG performance.

Keywords Matrix Converter (MC), Direct Torque Control (DTC), Particle Swarm Optimization (PSO), Modified PSO, Modified hybrid PSO, Mutation PSO, SMPSO, Doubly Fed Induction Generator, Energy Management, Wind Energy Conversion System.

1. Introduction

There is a drastic reduction of conventional energy sources and enhancement of non-conventional energy sources. In the last two decades, considerable efforts are kept to make electricity from renewable sources of energy. The best advantages of using renewable are abundance and lack of harmful emissions. Wind energy is the most abundantly available renewable source of energy in nature. The wind energy can be harnessed by a Wind Energy Conversion System (WECS), consists of a wind turbines, electric generator, a power electric converter and the corresponding control system. In wind turbines, mechanical power of the blades is shifted to the turbine rotor either directly or using a gearbox. The wind turbine can either operate at fixed speed or variable speed. There are several reasons for using a variable speed wind turbine over fixed speed wind turbines as they causes a mechanical stress reduction, noise, possibility to control active and reactive power and provides maximum power tracking from a wind turbine. The DFIG is considered to be the most common configuration used for large variable speed wind turbine that the connected to an AC power grid [1-2].

The classical DTC is a highly dynamic and high performance control technique for induction machine drives as indicated takahashi [3]. The DTC scheme using switching table has some drawbacks switching frequency varies according to the speed and the hysteresis bands of the torque and flux. A large torque ripple is generated is the low speed range and high control sampling time is required to achieve good performance. DTC is used to combine to MC to obtain a fully controlled DFIG and improve the performance of classical DTC [4,52-54]. The block diagram of the DFIG based AC- AC, MC represented in Figure 1.

The power electronic converters used for wind energy conversion will exhaust the reactive power that is not easy to control and also they produce the harmonics due to high switching frequency [5]. The filters are required to eliminate the higher order harmonics [6]. MC is an AC-AC converter, converts AC-AC directly with different voltage and current parameters. The fundamental difference between the MC and the AC-DC-AC converter is that MC converts AC power without any intermediate elements like capacitor and inductor (or) energy storage elements [5-7]. Absence of large storage elements, MC is compact in size with long life apart from the above advantages [8-10]. Software adopted control structure lead the matrix converter to an interesting research topic for the last few decades. The MC has a bidirectional power flow capability; it consists of bidirectional power switches. The most useful MC has 3 phase input and 3 phase output, the detailed studies of MC, tremendous research work both in simulation and experimental studies about the topology and control methods have been analysed and published in various literatures along with the development of power semi-conductor switches. In MC for three phases, AC-AC converter consists of 9 bidirectional switches arranged in 3X3 matrix shape. In each switching period, duty ratio of each power semiconductor switch is changed according to the applied control strategy, so as to produce the output voltage and current with required amplitude and frequency [11-12]. The detailed control techniques of MC are represented in Figure 2.

The first details were explained in 1971 and 1976 by Pelly B using the name thyristor phase controlled converter and static power frequency changers respectively [13-14]. In 1980 Venturini et al proposed the name Matrix Converter (MC) as generalized transformer, the proposed MC can increase or decrease the voltage magnitude, frequency, phase and power factor from input and output. In 1989 the same authors proposed an improved method from the previous one to increase the voltage transfer ratio 0.866 from 0.5 [15]. The first method is called Venturini method and the second one is called as an improved Venturini method. In the year 1987, Roy G, et al proposed simple control technique named as scalar control. The switching pulses were calculated directly from measurements of the input phase voltages. This method has the limitation that is the voltage transfer ratio is limited to 0.5 similar to the Venturini method [16-18]. The Space Vector Pulse Width Modulation (SVPWM) technique has the capability to achieve full control of both the input current displacement angle and output voltages [19-21]. The Model Predictive Control (MPC) technique is a software based simple technique for switching and controlling of harmonics by introducing observers, thereby reducing the number of voltage and current sensors [22]. This technique still produces small content of harmonics [23]. The soft computing algorithm based techniques still reduces the harmonics of MC [41]. Apart from the above mentioned major contributions, so many advanced modulation strategies PSO based MC [24] fuzzy logic controller [25, 42] Neuro fuzzy [26] Genetic Algorithm (GA) [27] Hybrid PSO [28] crazy PSO [29] were analysed for minimizing the objective function.

The problem of harmonic can be reduced by the above techniques; another problem with the induction motor drive is torque control. The different methods were explained in the literature. The closed loop adaptive speed observer introduced to enhance the dynamic behaviour of MC fed stator flux oriented DTC induction motor Drive [30]. DTC method for sensor less IM fed MC drive was proposed with less torque ripple and input power factor control. The combination of advantages of MC with DTC strategy using SVM was illustrated. The over modulated strategy proposed to overcome the degradation of dynamic torque response compared to the basic DTC method [31]. DTC for the IM fed indirect matrix Converter (IMC) was presented in [32]. This IMC for input current is applied to the rectifier bridge, while the output voltage is applied to the inverter bridge. The control process can be separated into two modulation process (rectifier stage modulation + inverter stage modulation). The two-stage MC (TSMC) exclusively for bi-directional power flow, and high quality input/output waveforms. The novel direct torque control method for induction motor drive system fed by TSMC, control of AC/DC separately proposed in [33]. The New control scheme based on hybrid particle swarm Optimization, The controller uses the information provided by the torque and stator flux errors to modify the standard DTC voltage vector selection process [34]. A method presented for current control of an IM fed by MC effectively controls the output current from the MC to the machine and the reactive input current to the system [35]. In [36] presents a fuzzy logic controller for a direct torque control of MC fed IM. In [39] presents a new control technique for direct torque control of three-phase IM fed by IMC using fuzzy logic technique. The simulation results of different controllers are compared to get the effective performance of the MC. The motivation of behind this paper is that the advantages of DFIG with MC perfectly suitable for the variable speed wind energy conversion process. The best results can be obtained using the interaction of the DFIG with MC. The proposed new modulation algorithm uses the mutated PSO were implemented. The simulation and hardware results were tested on the test system. The proposed control method exhibits the best performance compared to the conversion methods. The proposed controllers operate on the unity power factor control, i.e. input power factor control is possible with the proposed techniques. The simulation outcome exhibits the strength of suggested controllers to reduce harmonics. The prototype hardware results indicate the same results with the software. This paper is organized as follows. The description of the mathematical modeling of MC is presented in section II. The mathematical analysis of a wind turbine and DFIG modeling is discussed in the section-III. The proposed control strategy explained in section IV. The results obtained by simulation of DFIG-MC and IM-MC are presented in section V. In section VI describes the hardware results. Section VII concludes the paper.

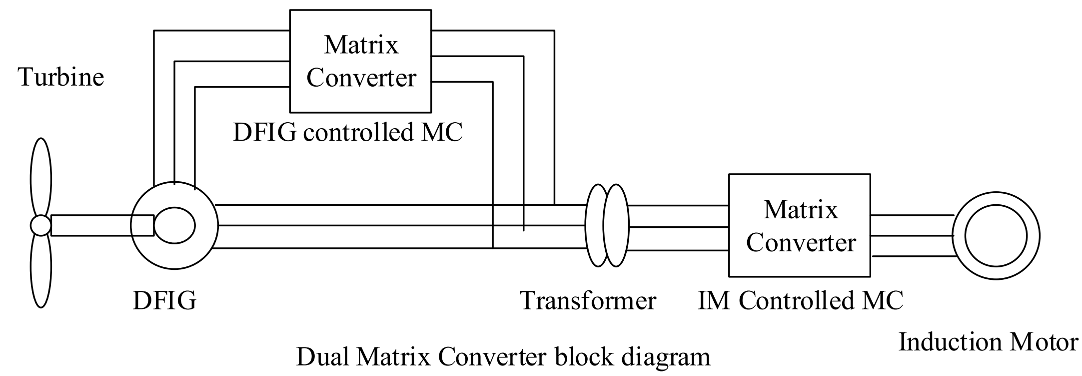

Figure 1 Block diagram of Dual Matrix Converter

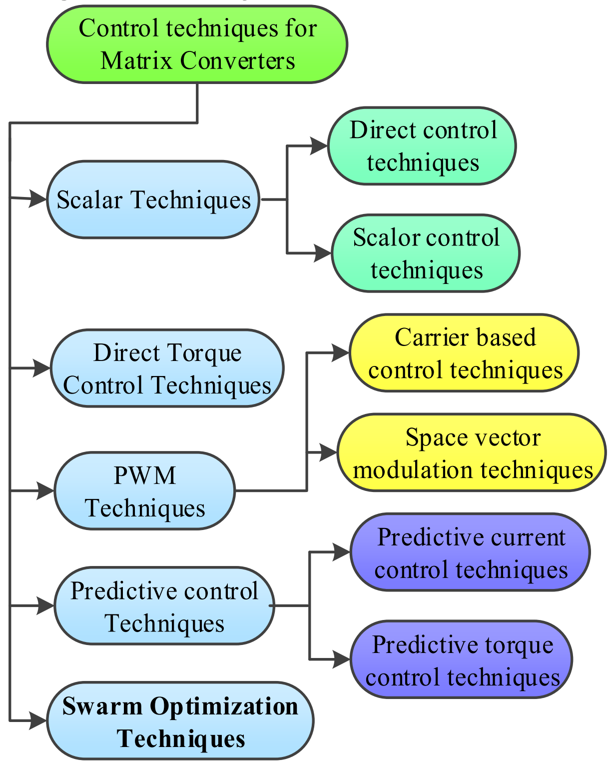

Figure 2 Different types of control techniques for Matrix Converters

2. Mathematical Modeling of Matrix converter

The comprehensive model includes all normal functions of MC i.e. control of the output voltage magnitude, output frequency input displacement power factor [39]. The model is in qdo reference frame for the MC input and output voltage and current fundamental component. Transformation Matrix should satisfy the following requirements i) Restrictions on duty cycle ii) Sinusoidal output voltages with controllable frequency, magnitude iii) Sinusoidal input current with controllable power factor.

The transformation Matrix is two basic solutions (Eq.1-Eq3) that individually satisfy

$$D_1 = \frac{1}{3}\begin{bmatrix} 1+2q\cos(\theta_{s1}) & 1+2q\cos(\theta_{s1}-2\pi/3) & 1+2q\cos(\theta_{s1}+2\pi/3) \\ 1+2q\cos(\theta_{s1}+2\pi/3) & 1+2q\cos(\theta_{s1}) & 1+2q\cos(\theta_{s1}-2\pi/3) \\ 1+2q\cos(\theta_{s1}-2\pi/3) & 1+2q\cos(\theta_{s1}+2\pi/3) & 1+2q\cos(\theta_{s1}) \end{bmatrix} \quad (1)$$

$$D_2 = \frac{1}{3}\begin{bmatrix} 1+2q\cos(\theta_{s2}) & 1+2q\cos(\theta_{s2}-2\pi/3) & 1+2q\cos(\theta_{s2}+2\pi/3) \\ 1+2q\cos(\theta_{s2}+2\pi/3) & 1+2q\cos(\theta_{s2}) & 1+2q\cos(\theta_{s2}-2\pi/3) \\ 1+2q\cos(\theta_{s2}-2\pi/3) & 1+2q\cos(\theta_{s2}+2\pi/3) & 1+2q\cos(\theta_{s2}) \end{bmatrix} \quad (2)$$

$\theta_{s1}=\omega_i t-(\omega_o t+\alpha_o)$

$\theta_{s2}=\omega_i t-(\omega_o t+\alpha_o)$

$\omega_i t=2\pi f_i$

$\omega_o t=2\pi f_o$

$q=V_{om}/V_{im}$

f_i =MC input frequency

f_o =MC output frequency

V_{om} =peak value of output voltage magnitude

V_{im} =peak value of input volatge magnitude

$$D = aD_1 + (1-a)\,D_2 \quad (3)$$

a= constant parameter varying between 0 and 1

Output voltage and input current of MC (Eq.4-Eq.5)

$$\overline{V_{abc}} = V_{im}\begin{bmatrix} \cos(\omega_i\, t) \\ \cos(\omega_i\, t - 2\pi/3) \\ \cos(\omega_i\, t + 2\pi/3) \end{bmatrix} \tag{4}$$

$$\overline{V_{ABC}} = S\overline{V_{abc}} = (as_1 + (1-a)s_2)\overline{V_{abc}}$$

$$= qV_{im}\begin{bmatrix} \cos(\omega_o\, t + \alpha_o) \\ \cos(\omega_o\, t + \alpha_o - 2\pi/3) \\ \cos(\omega_o\, t + \alpha_o + 2\pi/3) \end{bmatrix} \tag{5}$$

Output currents (Eq.6-Eq.14)

$$\overline{i_{ABC}} = I_{om}\begin{bmatrix} \cos(\omega_o\, t + \alpha_o + \varphi_o) \\ \cos(\omega_o\, t + \alpha_o + \varphi_o - 2\pi/3) \\ \cos(\omega_o\, t + \alpha_o + \varphi_o + 2\pi/3) \end{bmatrix} \tag{6}$$

$$\overline{i_{abc}} = D^T\,\overline{i_{ABC}} = qI_{om}\left\{ a\begin{bmatrix} \cos(\omega_i t + \varphi_o) \\ \cos(\omega_i t + \varphi_o - 2\pi/3) \\ \cos(\omega_i t + \varphi_o + 2\pi/3) \end{bmatrix} + (1-a)\begin{bmatrix} \cos(\omega_i t - \varphi_o) \\ \cos(\omega_i t - \varphi_o - 2\pi/3) \\ \cos(\omega_i t - \varphi_o + 2\pi/3) \end{bmatrix} \right\} \tag{7}$$

$$\overline{i_{abc}} = i_{im}\begin{bmatrix} cos(\omega_i\, t + \varphi_i) \\ cos(\omega_i\, t + \varphi_i - 2\pi/3) \\ cos(\omega_i\, t + \varphi_i + 2\pi/3) \end{bmatrix} \tag{8}$$

Where φi is the input displacement angle

$$qI_{om}\left\{a\cos(\omega_i\, t + \varphi_o) + (1-a)\cos(\omega_i\, t + \varphi_o)\right\} = I_{im}\cos(\omega_i\, t + \varphi_i) \tag{9}$$

$$\begin{aligned} qI_{om}\left\{\cos(\omega_i\, t)\right\}\cos(\varphi_o) + (1-2a)\sin(\omega_i\, t)\sin(\varphi_o)\} \\ = I_{im}\{\cos(\omega_i\, t)\cos(\varphi_i) - \sin(\omega_i\, t)\sin(\varphi_i)\} \end{aligned} \tag{10}$$

$$qI_{om}\cos(\varphi_o) = I_{im}\cos(\varphi_i) \tag{11}$$

$$qi_{om}(1-2a)\sin(\varphi_o) = -I_{im}\sin(\varphi_i) \tag{12}$$

$$a = \frac{1}{2}(1 + \frac{\tan\varphi_i}{\tan\varphi_o}) \tag{13}$$

$$DPF_{in} = \cos\{\tan^{-1}[(2a-1)\tan(\cos^{-1}/DPF_{out})]\} \tag{14}$$

Where DPFin = cos (φi) and DPFout= cos (φo)

3. Modeling of wind turbine and DFIG

a. Wind turbine model:

The algebraic relation between wind speed (V_w) and mechanical power extracted (Pm) is described by the following relation (Eq.15-Eq.18)

$$P_m = 0.5\rho A V_w^3 C_p(\lambda,\beta) \tag{15}$$

$$C_p(\lambda,\beta) = 0.5(116/\lambda_i - 0.4\beta - 5)e^{(21/\lambda_i)} \tag{16}$$

$$\lambda_i = (1/(\lambda + 0.08\beta) - 0.035/\beta^3)^{(-1)} \tag{17}$$

$$\lambda = W_t / V_t$$

(18)

The mechanical torque of the turbine is expressed as (Eq.19)

$$T_m = P_m / W_t \tag{19}$$

The power coefficient C_p of a wind turbine is not constant, but raises with wind speed, rotational speed of the turbine and the pitch angle (β). In practice a wind turbine generator with good blade, C_p may reach a value of 0.5.

b. Doubly fed Induction generator model

The mathematical dynamic model of DFIG in d-q form can be written as follows (Eq.20-23)

$$\frac{1}{W_b}\frac{d\psi_{ds}}{dt} = R_s i_{ds} + \omega_s \psi_{qs} + V_{ds} \tag{20}$$

$$\frac{1}{W_b}\frac{d\psi_{qs}}{dt} = R_s i_{qs} + \omega_s \psi_{ds} + V_{qs} \tag{21}$$

$$\frac{1}{W_b}\frac{d\psi_{dr}}{dt} = R_r i_{dr} + (\omega_s - \omega_r)\psi_{qr} + V_{dr} \tag{22}$$

$$\frac{1}{W_b}\frac{d\psi_{qr}}{dt} = R_r i_{qr} + (\omega_s - \omega_r)\psi_{dr} + V_{qr} \tag{23}$$

d-q stator and rotor fluxes are described (Eq.24-Eq.27)

$$\psi_{ds} = -(L_{ls} + L_m)i_{ds} - L_m L_{dr} \tag{24}$$

$$\psi_{qs} = -(L_{ls} + L_m)i_{qs} - L_m L_{qr} \tag{25}$$

$$\psi_{dr} = -(L_{lr} + L_m)i_{dr} - L_m L_{ds} \tag{26}$$

$$\psi_{qr} = -(L_{lr} + L_m)i_{qr} - L_m L_{qs} \tag{27}$$

The electrical active and reactive power delivered by the stator (Eq.28-Eq.29)

$$P_s = \frac{3}{2}\frac{P}{2}(V_{ds}i_{ds} + V_{qs}i_{qs}) \tag{28}$$

$$Q_s = \frac{3}{2}\frac{P}{2}(V_{ds}i_{qs} + V_{qs}i_{ds}) \tag{29}$$

The electrical active and reactive power delivered by the rotor circuit is given by (Eq.30-Eq.31)

$$P_r = \frac{3}{2}\frac{P}{2}(V_{dr}i_{dr} + V_{qr}i_{qr}) \tag{30}$$

$$Q_r = \frac{3}{2}\frac{P}{2}(V_{dr}i_{qr} - V_{qr}i_{dr}) \tag{31}$$

The electromagnetic torque based on rotor fluxes and rotor currents can be expressed as (Eq.32)

$$v_i^{t+1} = \omega.v_i^t + C_1 r_1 \left(Pbest_i^t - s_i^t\right) + C_2 r_2 \left(Gbest^t - s_i^t\right) \tag{33}$$

$$S_i^{t+1} = S_i^t + V_i^{t+1} \tag{34}$$

Where

t= 1, 2, 3,….n and n is the size of the swarm

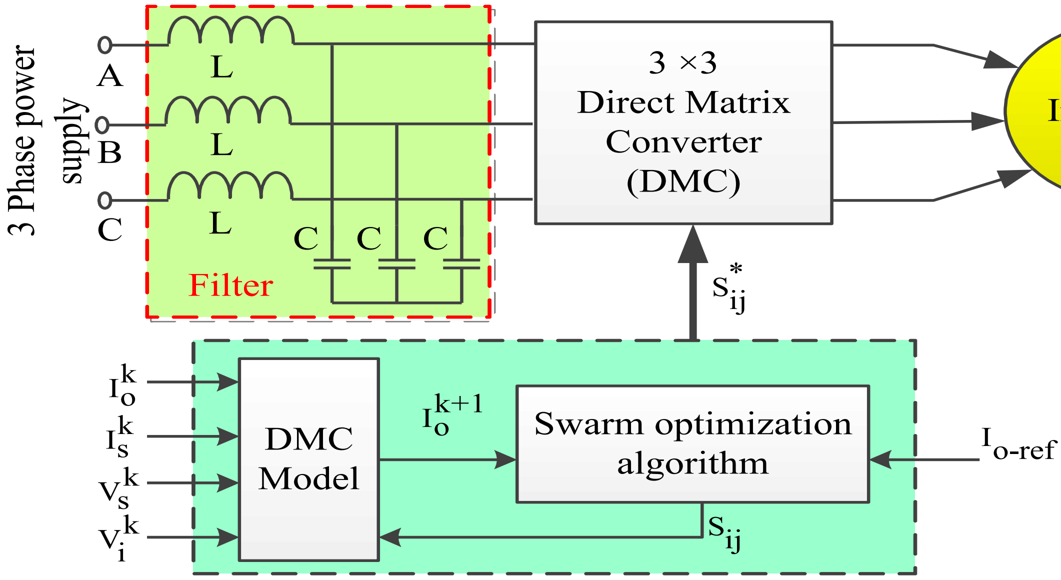

Figure 3 Optimized switching strategy determination with swarm optimization controllers

ω= inertia weight factor

C1, C2= position constants

r1, r2= random numbers

Pbesti= the best previous position of the ith particle Gbest= best particle among all the particles in the swarm

In the typical PSO algorithm, the inertia weight vector ω ranges 0.9 to 0.4 and regulates the previous involvement of the particles. The step wise PSO algorithm is shown below

Step 1: By using state variables, the velocities and search points are randomly generated. The position of a the agent can be served as (35)

Step 2: Velocity of particular fragment can be adjusted by using (Eq.33)

$$S_{ij}^K = \begin{bmatrix} S_{11}^k & S_{12}^k & S_{13}^k \\ S_{21}^k & S_{22}^k & S_{23}^k \\ S_{3}^k & S_{32}^k & S_{33}^k \end{bmatrix} \tag{35}$$

Step 3: A velocity, which moderately gets the situation close to Pbest and Gbest can be updated by (Eq.34). The adjustment of a searching point by PSO and the behavior of particle in a search space move towards the best position.

Step 4: The fitness function is consummated from the objective function. The objective function is the value obtained in the Simulink model using THD

4. Proposed control techniques

The test system considered in this study consist of a three phase 3*3 MC, which is fed by a three phase voltage source through an input LC filter to drive the induction motor load for getting variable voltage and current. To control the switching states, different types of swarm optimization based control techniques are suggested. The new optimized switching strategy with proposed swarm optimization controllers is represented in Figure 3. The swarm optimization algorithms are based on the food finding behavior of the animals which can optimize the problem literally as per the given rules and procedures.

4.1 Particle Swarm Optimization technique

PSO algorithm was first proposed by Kennedy and Eberhart in 1995, based on the food finding behavior of the bird flocks [43-44]. Due to its speed of response, better solutions and shorter programming codes it is separated from the other techniques. The particles which produce the hidden solutions are used in this technique. Each particle rides in the free space with a certain velocity, which can be controlled with previous experiences. The draft situation of the particle of the swarm, with a particle velocity, at iteration is defined as (Eq.33-Eq.34) block available in the library. The fitness function of each particle in the initial position is calculated using mathematical modelling of matrix converter. Based on the switching matrix (Eq.35) The initial best calculated value among Pbest is set as Gbest.

Step 5: The fitness function values are evaluated to update the position of the particles as presented in Figure 4 the fitness function in this paper is the output voltage THD value of the MC.

Step 6: If the terminating criteria are met, the method stops. The stopping criteria are nothing but the net difference between two consecutive iterations is less than 1 or six iterations. The six iterations are chosen because of the selection time for the optimum switching state must be less the sampling time.

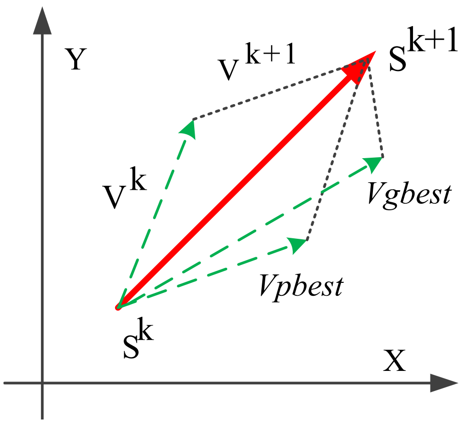

Figure 4 Approach of adjustment of a searching point by PSO

The arithmetic mean is enforced in Pbest, Gbest and velocity renews calculations to utilize the old history of the positions and velocities. The early three iterations of the Pbest values are determined and stored in an array for the next iteration. The arithmetic mean is enforced to the previous iteration and stored Pbest values to get the new Pbest value. Thus the same formula is followed in calculating Gbest and velocity updates [45].

4.2. Modified Particle Swarm optimization

The arithmetic mean is enforced in Pbest, Gbest and velocity renews calculations to utilize the old history of the positions and velocities. The early three iterations of the Pbest values are determined and stored in an array for the next iteration. The arithmetic mean is enforced to the previous iteration and stored Pbest values to get the new Pbest value. Thus the same formula is followed in calculating Gbest and velocity updates [45].

4.3. Modified Hybrid Particle Swarm Optimization

The solution quality was improved rapidly with the use of MPSO technique. The local search methods will get the solution to optimization problem early [46]. By utilizing the effectiveness of both local search technique and PSO technique, the new optimization technique is developed with more efficiency called MHPSO [47]. Hence MHPSO algorithm operates in two stages.

Stage 1: By the use of MPSO technique, optimal area is obtained early

Stage 2: Direct search technique is employed for getting the optimized result

4.4. Cauchy Mutation PSO (CMPSO)

The mutation PSO techniques are used to eliminate the loss of diversity problems in the PSO [50]. If the searching neighbours are added in each immediate production, the search space is extended. It is used in the CMPSO to get overall best position of each particle. The CMPSO operator is characterized by (Eq.36) to get the optimal result

$$\omega(i)=\frac{\sum_{j=1}^{N} v[j][i]}{N} \tag{36}$$

4.5. Adaptive Polynomial Mutation PSO (APMPSO)

The current position and velocity will decide the new position in the PSO algorithm [48-49]. The individual Pbest and Gbest will influence the current velocity of the particle. If Gbest changes, the velocity of the particle also changes and the new particle searches the other regions for better values. At the end of each rule the particles are mutated with the equations (Eq.37)

$$S_{ij}=S_{ij}+\sigma^{*}\exp(\tau F(0,1)+\tau' F_j(0,1)) \tag{37}$$

4.6. Sobol Mutation PSO (SMPSO)

The SMPSO is familiar with improving the behaviour of the basic PSO algorithm [51]. The recommended SM operator is defined as

$$SM=R_1+\left(R_2 / \ln R_1\right) \tag{38}$$

Where R_1 and R_2 are the accidental numbers in the sobol progression.

The quasi arbitrary number used by the SM dealer permits the best particle to improve consistency and helps in seeking the search space further efficiencies. The suggested method star like the standard PSO algorithm up to the point of examining the position and acceleration of the particles. Then the Sobol mutation is applied to build a disturbance in the population. The comprehensive algorithm containing SMPSO presumed below

Step 1: Program the seed in the population.

Step 2: Computerize x[i] with systematically distributed random data.

Step 3: Calculate the objective function of x[i] as well as designate the cost of fitness [i]

Step 4: Program Pbest [i] using a replicated value of x[i]

Step 5: Compute Pbest – fitness [i] having a replicate in regard to fitness [i]

Step 6: Reiterate prior to stopping touchstone is attained for every particle [i]
Step 7: Revise v[i] as well as x[i]
Step 8: Revise Pbest as well as Gbest with the fitness values
Step 9: Sobol mutation
Discover an advanced particle with the use of SM agent (Eq.38-Eq.39)

$$TX=R_1+\left(R_2 / \ln R_1\right) \tag{38}$$

$$f\left(TX\right)<f\left(Pbest\right) \qquad Pbest=TX \tag{39}$$

5. Simulation Results

Each of the proposed controllers was tested on the matrix converter model expressed in the previous section. In PSO algorithm, the inertia weight ω is regarded crucial for PSO convergence. The inertia weight work to control the impact of the earlier history of velocities on the current one. Correspondingly, the parameter ω, control the trade-off surrounded by global and the local examination skills of the swarm. An acceptable significance for the inertia weight ω generally provides balance between global and local exploration qualifications and subsequently result is a contraction of the number of iterations required to find the optimum result. The maximum weight is fixed to 0.9 and minimum weight is set to 0.4. The existing conditions of C1 and C2 don't seem to be essential for the convergence of PSO. On the other hand, correct sophistication can result in faster convergence and mitigation of local minima. An extensive depiction of the stimulation parameter is the first variation of the PSO. The acceleration factors C1 and C2 equal to 2. The existing conditions of rand1 and rand2 are used to deal with the diversity of the population additionally they are uniformly distributed in the area [0, 1]. Figure 5 shows the fitness values for each technique with iterations. Table 1 represents fitness values of all optimization methods. The Figure 6 to Figure 9 shows the output voltage waveforms and THD analysis with IM as a load for PSO, MHPSO, CMPSO and SMPSO techniques as controllers. The simulation models results the best results of each percentage of THD method after the termination criteria that 9.02, 7.68, 8.21 and 5.02 for the techniques PSO, MHPSO, CMPSO and SMPSO respectively. In Figure 12 the three phase voltages were shown. The three phase output currents were shown in Figure 10. The Figure 11 shows the input voltage and current so that the MC operates on the unity power factor. The DTC control of IM drive was implemented, the Figure 13 represents the Flux space vector trajectory. The output voltage of DFIG controlled MC is represented in Figure 14. The results obtained at the end of each optimization method were cumulatively explained. Different optimization based control methods were analysed on the same load condition. In all the results the input currents of MC are obtained to be sinusoidal. It is also identified that the minor harmonic content in the input current and output voltage still present. According to IEEE 519 the voltage harmonics in power system 69KV should be limited to below 5% THD. When the Obtained results were compared with the similar work done in the reference [41], there is no much difference between the values obtained and the literate values, but the minor improvement in output voltage harmonic content. Other future of the proposed method is that the simulation time is comparatively less with in the 6 iterations the fitness value reaching its optimum value. The major drawback of the proposed method is that the obtained output voltage harmonic value is more than the standard value. So, this work has the scope study further to reduce the harmonic content below the specific value using advanced metaheuristic optimization algorithms.

6. Experimental investigations with SMPSO

The fabricated MC fed IM drive test system model were shown in the figure 16.For proper operation of any power semiconductor switch, gate drive circuit is required. The gate drive circuit and IGBT switching module shown in the Figure 17. In Figure 18 shows the 6 IGBT switches for one leg implementation. Experiments are carried out to verify the validity of the proposed SMPSO with an induction motor drive for the matrix converter. Each and every iteration end the optimal switching states were stored and applied finally to the MC. In this experiment the stator currents are almost sinusoidal and stator voltage with less ripple content. The Matrix Converter hardware model can be designed using microcontroller, but the implementations of 9 switching pulse are difficult with the microcontroller. The delay time and commutation time are in such a way that it should not create the open circuit at output and short circuit at the input, for this specific purpose FPGA sparton-6 is chosen for generation of switching pulses shown in Figure 15. In the MC, there will be overvoltage that should be managed, the source of overvoltage is grid perturbation and fault states in the load. A conventional and standard way is to use a clamp circuit. In normal operation of MC, the diode is off, the clamp circuit has no influence on the MC operation. In hardware model 18 IGBT switches are used, rated 15A, 1200V (FGH15T120SMD), the other hardware parameters are listed in Table II for R-L and induction motor loads. The fabricated model output current waveform of the MC shown in Figure 19. In Figure 20 output voltage waveforms were shown. Input voltage and current waveforms of the fabricated MC fed IM test system were represented in Figure 21.

Table 1: Prototype parameters

Name of the Parameter		Value
V_s	Source voltage	380V
f_s	Source frequency	50 Hz
I_o	Load current	10 A_{pp}
f_o	Load frequency	50Hz
L_f	Filter inductance	30mH
C_f	Filter capacitance	150uF
R_f	Filter resistance	0.5 ohms
L_o	Load inductance	15mH
R_o	Load resistance	10 ohms
T_s	Sampling time	50us

Table 2: Simulation of results for different techniques

Method	1st iteration	2nd iteration	3rd iteration	4th iteration	5th iteration	6th iteration
PSO	21.76	19.67	15.15	12.39	10.12	9.02
MPSO	21.76	18.3	14.12	12.01	9.98	8.12
MHPSO	21.76	18.12	13.92	11.12	10.1	7.68
CMPSO	21.76	16.02	14.32	12.22	9.79	8.21
APMPSO	21.76	15.12	14.15	11.59	8.89	7.56
SMPSO	21.76	15.13	12.15	10.89	7.23	5.02

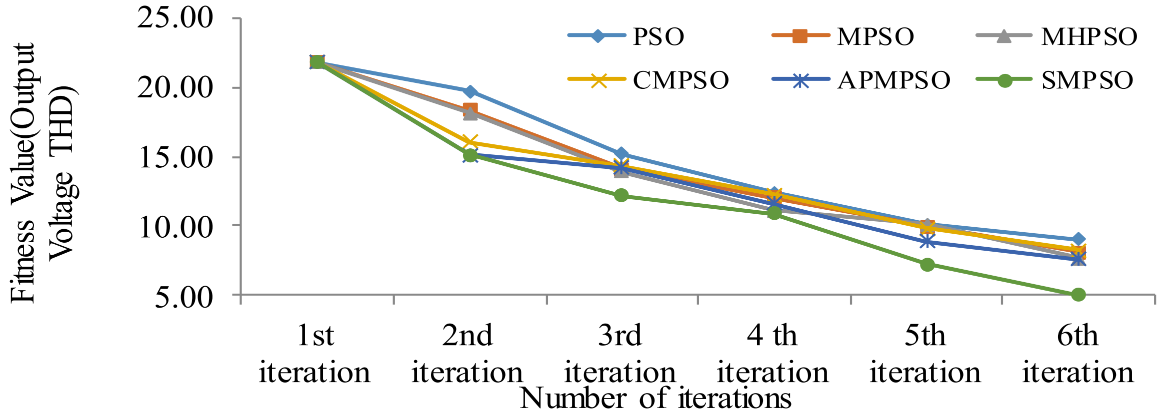

Figure 5 Fitness value of each iteration of different PSO methods

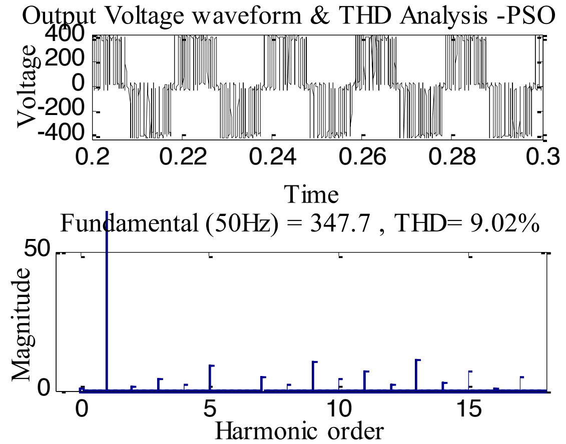

Figure 6 Output load voltage and THD of PSO technique

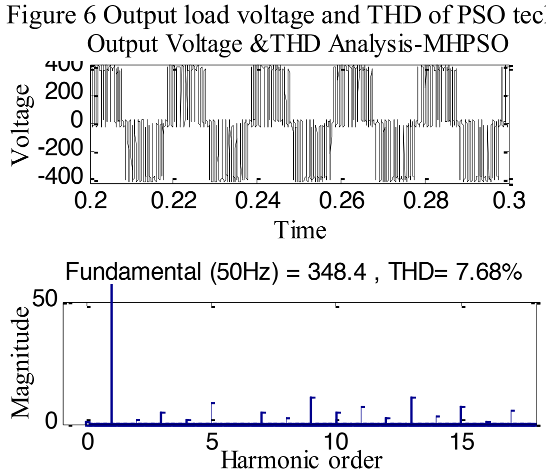

Figure 7 Output Voltage and THD analysis of MPSO technique

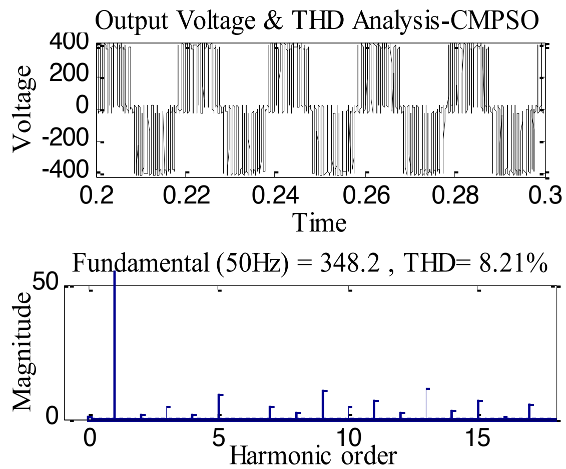

Figure 8 Output load voltage and THD analysis of CMPSO technique

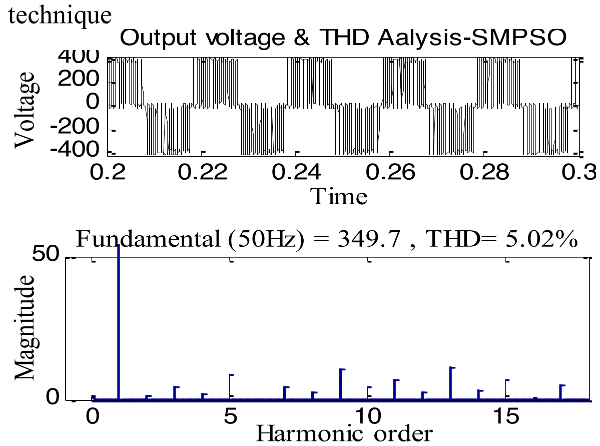

Figure 9 Output Voltage and THD analysis of SMPSO technique

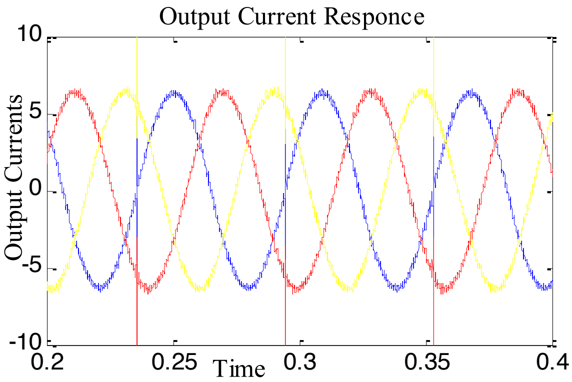

Figure 10 Three phase output Current wave forms of IM Controlled MC

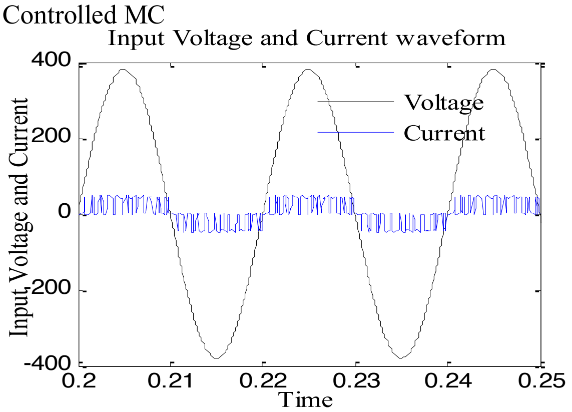

Figure 11 Input current and voltage waveforms of DFIG controlled MC

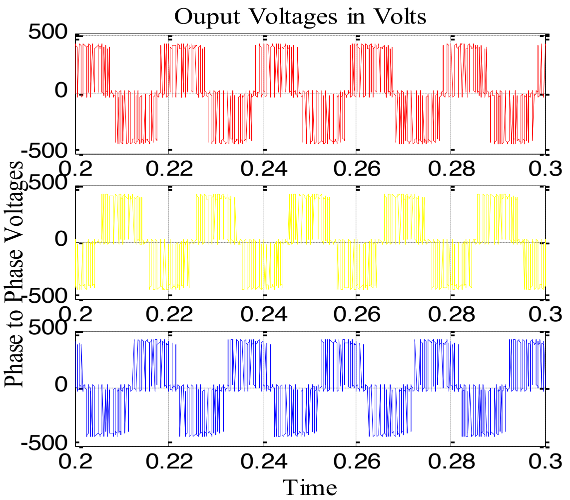

Figure 12 Three phase output load voltages

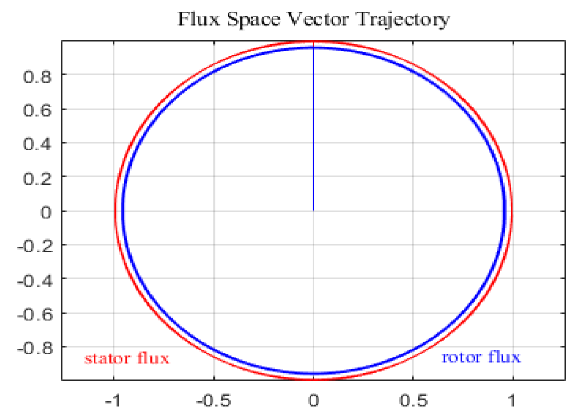

Figure 13 Flux Space Vector Trajectory

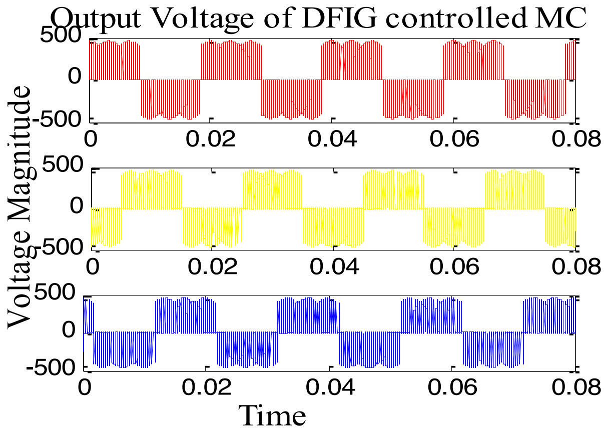

Figure 14 Output voltage waveform of DFIG controlled MC

Figure 15 Control unit of Sparton -6 board

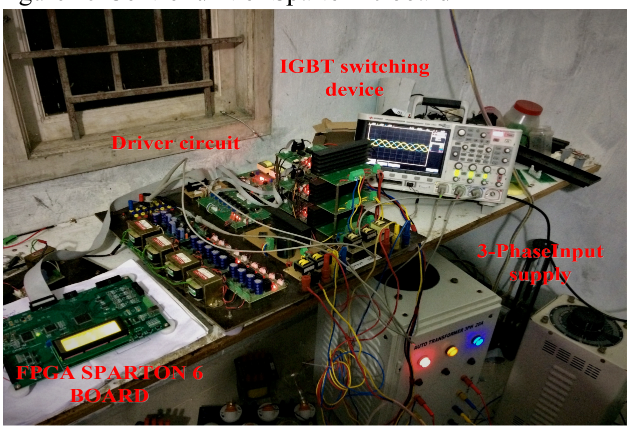

Figure16 Experimental setup of Dual MC

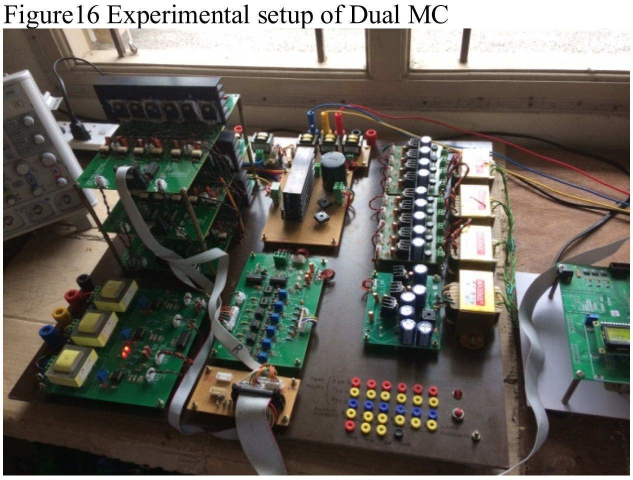

Figure 17 Driver circuit and IGBT switching circuit

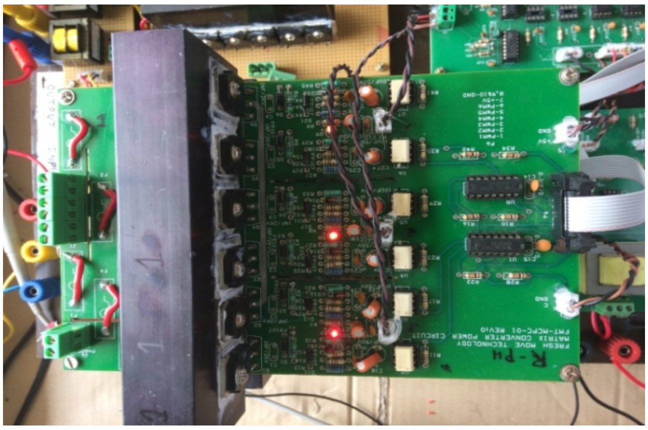

Figure 18 6 IGBT switches for one leg

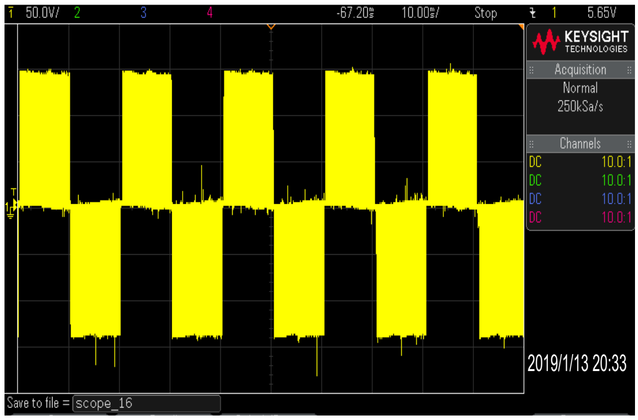

Figure 19 Hardware prototype output current waveform

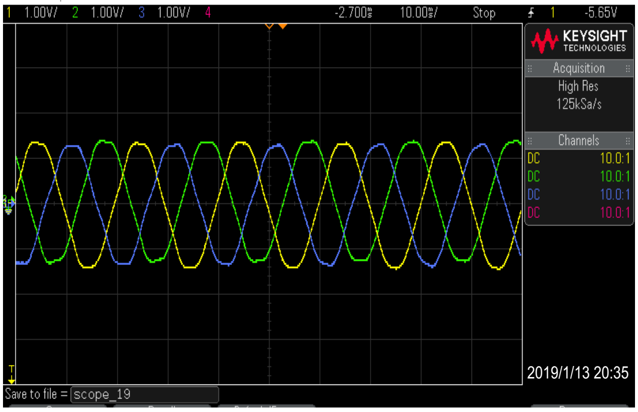

Figure 20 Hardware prototype output Voltage waveform

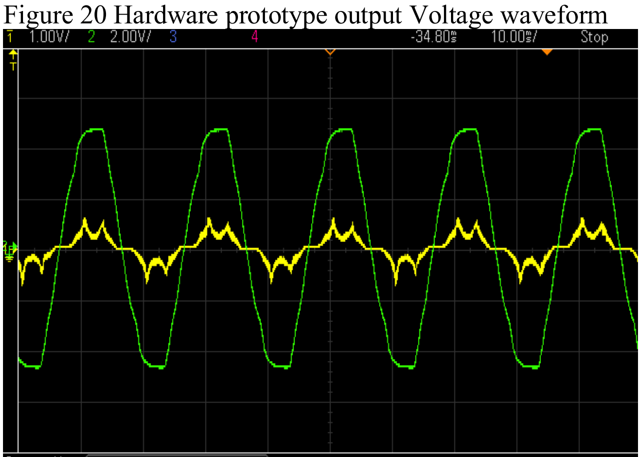

Figure 21 Hardware prototype input current & input voltage waveforms

7. Conclusion

This proposed mutated PSO based switching generation approach improves the control behaviour of MC systems. The proposed dual MC system for variable wind energy conversion system was successfully implemented in software and the MC fed IM Drive performance was implemented in the hardware. The suggested controller can line the three reference currents of the 3-phase system jointly and provides exhorted outputs successfully in the described load frequency. The complete evaluation of the algorithm shows that the control behaviour of SMPSO is more superior to the other. The consequences decrease the output voltage THD from 21.76% to 5.02%. The prospective method outcome was implemented using the hardware prototype with induction motor load and are validated. The proposed control strategy could be applied to the dual MC variable speed wind energy conversion system strongly. The future researchers can use the different advanced metaheuristic optimization techniques to further improvement of MC based wind energy conversion system

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