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Research Article

Review on Novel AI-Based Soft Computing Applications in Motor Drives

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Abstract – Novel Al-based soft computing applications are vital tools that have greatly upgraded the performance of electrical rotating machines both in design and control. The optimal performance of motors and electric vehicles greatly pends on soft computing techniques advancement in electrical rotating machines. This work presents the view of soft computing techniques and their various applications, most recent of the techniques are reviewed to give a deep inside for further design and control of motor drives.

Keywords – Soft Computing, Motor Drives, Algorithms, Electric Vehicles, AC, DC

I. INTRODUCTION

Novel Al-based soft computing techniques for effective control of industrial motor drive using artificial intelligence is rapidly gaining acceptance around the globe in industries to ensure accurate speed tracking referencing, efficient and robust energy utilization, and extension of the life span of the motor drive system while avoiding the condition saturation inrush current and minimization of the electric grid host systems[1]. Particle swamp optimization and genetic algorithms among others are increasingly over the years gaining wide acceptance over the years as effective tools for dynamic online turning, adjustment of controlled, rs, and self-regulating to ensure that specific objective functions are optimized and achieved[1]. In 1888 it was a milestone when three phase induction motor was developed by Nikola Tesla, today it is estimated that sixty-five percent of the energy generated by industrialized nations is used by electric drives, and variable, constant, and servo motor drives are in used in household, industries, electric tractions, aerospace, transportations, medical equipment among others, most of these are focussed on the current trend of power electronic technologies[2]. Electromechanical drives for speed control and positioning are vital in factory automation, robotics, process control, and energy conservation among others. However, in ac and dc motor drives, dynamic online self-adjusting-driven control strategies give efficient, robust, and effective control strategies. Induction motor in recent times has become one of the most popular electrical rotating machines and the advancement in power electronic has led to high performance and better efficiency in electric drives, to be able to meet up with the current demand[2], there is need for optimization, control, design of electrical rotating machines using the modern techniques, this can only be achieved using novel al based soft computing applications to replace knowledge-based method procedure, mathematical problems that are difficult to solve by traditional time-consuming classical mathematical tools an be approach using soft computing applications methods, al- based soft computing techniques brought numerous solutions to control and design of electrical machines[2]. This work review of genetic algorithm and particle swamp optimization among other methods are allowed by single and multiple objective search optimization algorithms and how the application of both techniques can be done to ensure optimum motor drives, hybrid photovoltaic-Fuel Cell–Diesel–Battery Electric Vehicle drive system among others[1].

The primary objective of this paper is to review the novel al-based soft computing techniques applications in motor drives using notable top pair-review articles concerning the subject matter, computing in design, development, and control of motor drives was carefully chosen to build the data based, the algorithms selected for this work are as follows; fuzzy, neural network, evolutionary computations, metaheuristics, genetic algorithm, and particle swamp. The study of soft computing techniques has been in existence in the late 80s and 90s this has helped to boost the development and design advancement in rotating electrical machines. Generally, the two optimization techniques based on genetic and particle swamp algorithms are single and multiple objective functions, single objective can be combined with other several objective functions by using the ng weighting factor and could be optimized with GA and PSO to obtain desired solutions. A set of acceptable trade-off optimal solutions can be obtained using multiple objective functions, and it helps the users to make good decisions through several solutions that are very optimum from a good standpoint. Figure 1 shows soft computing methods considered in this review[3][4]

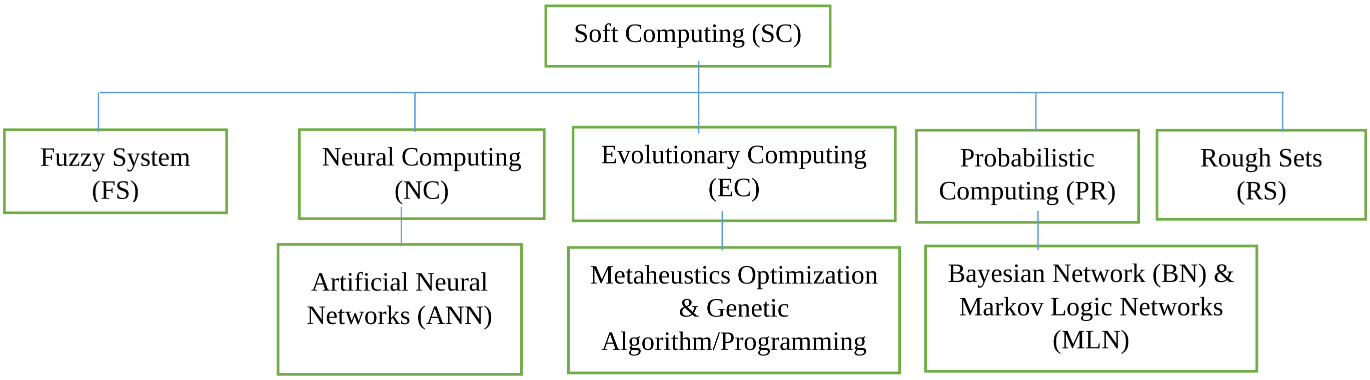


Fig. 1: Soft computing methods[5][6][7]

II. MATERIALS AND METHOD

1. Artificial intelligence based- motor drives

This consists of all-based controllers for induction machine drives, classical controllers using algorithms, Classical Controllers replaced by AI-based Controllers, and turning the hyper-Parameters of AI-Based Controllers Using Optimization Algorithms[8].

The tuning Classical Controllers Using Optimization algorithm under al-based controllers for induction machine drives utilizes proportional integral derivative (PID) controllers' type, this is widely used in the industries today because of their simple design, structures, and cost-effectiveness, one of the major challenges is the problem of finding best values for the parameters in using classical methods such as Ziegler -Nicholas method, frequency response, pole assignment using root locus, and trial and error method among others[2][8]. Some of the advanced control methods structures, such as modal reference adaptive, self-turning, and sliding mode control will always require certain degree parameters turning, consequently, various optimization algorithms can be applied to turn and control these parameters to ensure optimal control performance and operating conditions, in this c, a genetic algorithm is applied to turn the proportional integral controller speed, the optimized parameters will always give better performance and operating conditions, consequently when PID controllers are placed with the controllers of sliding mode, the parameters can be optimized using the genetic algorithms, the dynamic response using the optimized controller parameters proved to be better than the controllers of the sliding mode[9]. Al-based controllers are specifically designed to identify and for adaptive control of induction machines, because in the case of inductive motor drive PI/PID controllers cannot provide effective performance in the case of linear control plant as obtainable in induction machine drive system with linear dynamics, and therefore the invention of using artificial neural network (ANN) to control inverter drives was proposed for the first time. They can be used to control the desired switching pattern using the existing stator current, they have good performance, increasing speed execution, and good fault tolerance. The hyper parameter are used in al-based controllers are used in many optimization algorithms, and Lutheran be used to train membership functions and neural network variables of fuzzy logic controllers, for instance GA is fully developed to search for optimal learning rates of a recurrent fuzzy neural network (RFNN online[10].

Fig 2. Electric machines are driven by artificial intelligence[2].

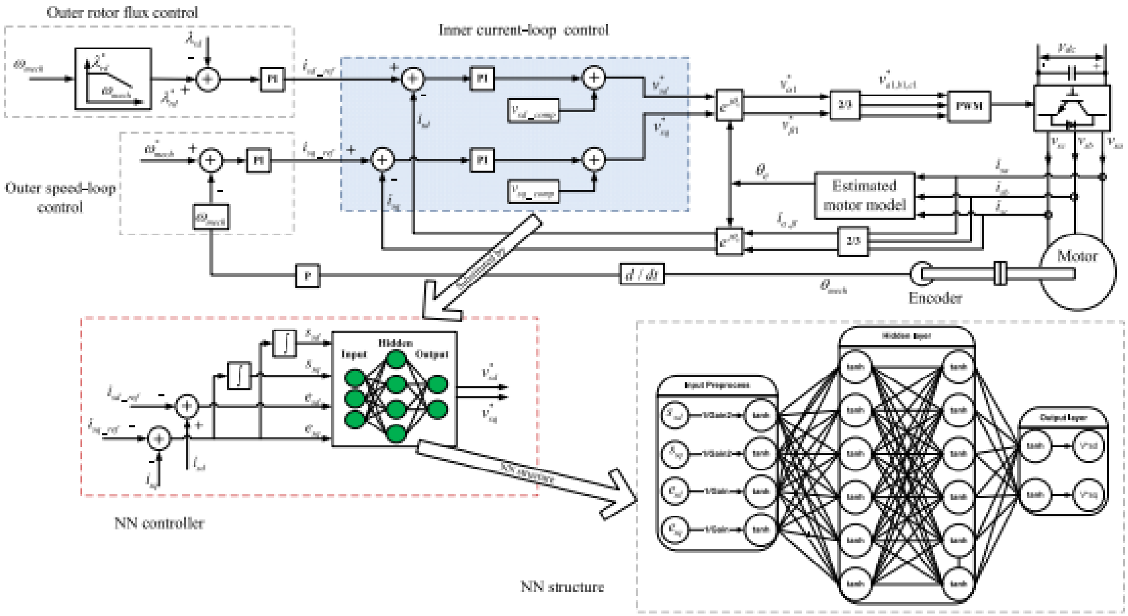


Fig 3. NN controllers substitute current looped PI controllers in conventional current control induction machines [2].

2. Fuzzy Systems.

The fuzzy logic system is used for ill-defined and modelling complex systems, its operation depends on the application of the variables which are better transformed into functions, it is the extension of Boolean classical logic where the logic statement is not true or false but can range from almost likely to certain. Simple fuzzy systems due to their high performance and applications are used in nonlinear controllers, this can be several methods of nonlinear control[2]. Fuzzy logic is very important in engineering practices and has many applications as shown in table 1.

Table. 1. Fuzzy system in rotating electrical machines[6][11].

S/n	Year	Application	Soft computing methods
1	2016	Used detection of fault and vibration	Mamdani type inference
2	2016	Used for the Power regulator	Fuzzy controller
3	2017	Used for brake control	Fuzzy logic
4	2018	Used for Conditioning monitoring of power	Fuzzy expert system

3. Hybrids Neuro-fuzzy.

The hybrids adaptive neuro-fuzzy inference system can always be combined or supported by mathematical tools when the need arises, the capabilities are higher due to better learning algorithms so that various parameters can be used, and they are applicable in nonlinear high control problems of electrical machines or assessment of condition issues, to be able to reduce harmonics of current and voltage and to improve total harmonics distortion and power factor[11][3]. Neuro fuzzy controller was used in hybrid passive filters for PWM rectifiers, consequently, a hydride approach was proposed for the classification and detection of the vibration signal of the induction motor where the fault detection process and the extraction of the features of the significant signal were done using the s-transformation algorithm[10], comparing s-transform -ANFIS, s-transform radial basis function neural network(RBFNN), s-transform-FNN and DWT-RBFNN where compared based on sensitivity, cantered or fault, specific IR fault condition, opposite or fault, BB fault condition, and orthogonal or fault and the result shows that S-transform ANFIS had the highest sensitively, accuracy and specificity and more advantages compare to other methods. When comparing fuzzy logic controllers, SNC, or ANFIS-based controllers it is evident that ANFIS-based VR-FCL is better in improving the stability of the transient large-scale hybrid power system, this shows that it has more efficiency and low energy consumption compare to the other methods[12][13].

Table 2. Hybrid techniques applied in electrical machine design and control[14][15]

S/N	Year	Application	Technique
1	2005	For the DC servo motor system	Robust model reference fuzzy controller
2	2015	For detection and classification signal of induction motor	S-transform algorithm and ANFIS
3	2015	Used for nonlinear controllers to augment a large power system	FLC, SNC & ANFIS
4	2017	Used for hybrid passive filter configuration proposed for PWM rectifiers	NFC

Table 2 shows the comparative analysis of hybrid technique as applied in electrical design and control, especially in motor drives, using different techniques and applications ranging from DC servo motor systems, detection, and classification of inductor motor signal, nonlinear controllers of large power system and hybrid passive filters configuration for PWM rectifiers. The graph shows the fuzzy logic controller compared to the hybrid -fuzzy controller using root mean square error(RMSE) for output cd tracking DC servo motor and invented pendulum, from the chart it is clear that the hybrid system has the best performance in terms of operation[11].

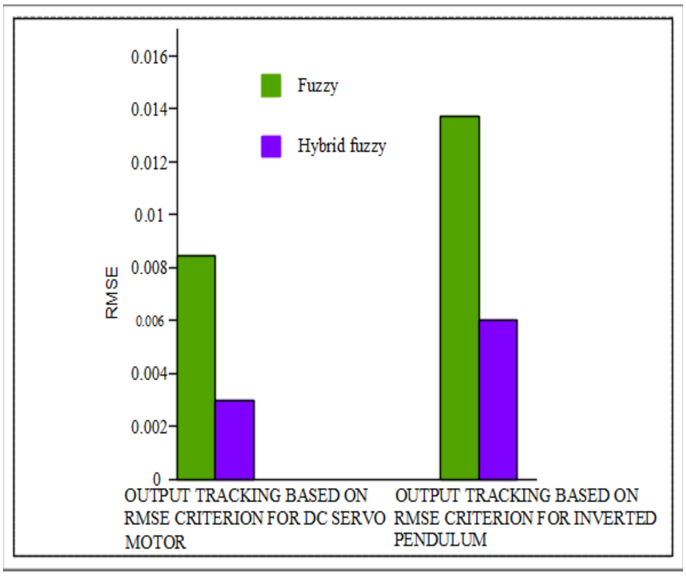


Fig 4. Tracking of servo motor and inverted pendulum.[2][14][16]

4. Artificial Neural Computing

The artificial neural network is one of the important tools in electrical engineering machines and other applications especially in motor drives, it is used to improve performance and efficiency in electrical rotating machines[2][8]. the application of hybrid PI-SMC and PI is easy, but the performance of the ANN-SMC controller is better in terms of error minimization and robustness, it has a higher power value compared to the experimental limits, reduction of high torque flux ripples, increase the performance and the stability of the terminal voltage[14][11]. The ANN-based technique has an efficient and economical way of stabilizing the voltage, consequently, it can be used for programmable array gate controller card on real-time system benchmark, it has one of the most predictable effects when it comes to simulation and can affect the performance of the system, it can be modelled using empirical data and according to the behaviours of the predictable function system which have more advantage compared to the fuzzy system, and therefore gives better performance to other techniques[15][17].

Table 3. Artificial neural networks[18][19][11][20].

S/N	Year	Application	Technique
1	2016	For Direct torque control of DFIM	ANN controller
2	2017	Used to Control multi-motor coupled system induction motors	ANN-SMC
3	2017	Used to estimate the output power and efficiency of AFP SG	multi-layer feedforward ANN
4	2018	Used for Voltage and frequency control of induction self-excited generator	ANN

5. Methods of evolutionary computation and Metaheuristics

This is used to optimize iterative problems through efforts of refining the functions of possible solutions to be able to achieve measure values, ant colony, evolutionary optimization, genetic algorithm is part of metaheuristic method consequently, evolutionary computation is methods of stochastic optimization where the random initial set of candidates are generated as the new generation are iteratively updated while mitigating the natural selection and mutation among others[20][21]. The problem of optimization can always be found in control and design, especially in electrical machines and drives system, the evolutionary methods can be used for nonlinear control task thereby reducing the computational cost. Consequently, genetic algorithm and differential evolution techniques can be combined to enable maximum average torque and torque density minimizing copper loss of a single-phase switch reluctance machine[22][5]. Surface-mounted and interior-mounted permanent magnet motors use evolutionary optimization algorithms such as differential evolution, but the metaheuristic optimization methods are more effective and can also be an alternative in such cases especially when it comes to sensor less drives, bat algorithm can be used with PID controller for the control of sensor less DC brushless electric motor, a modified genetic algorithm was also used with FOPID controller, it was clear that Bat algorithm had the best performance in times of settling time, peak and rise time and steady-state error. The graph below shows the settling time, rise time, peak time, and steady-state error for DC brushless electric motor drive for the Modified genetic algorithm

(MGA), Artificial bee colony (ABC), Bat algorithm (BA), Modified genetic algorithm (MGA) algorithms in 0,50, 100 percent full load[5].

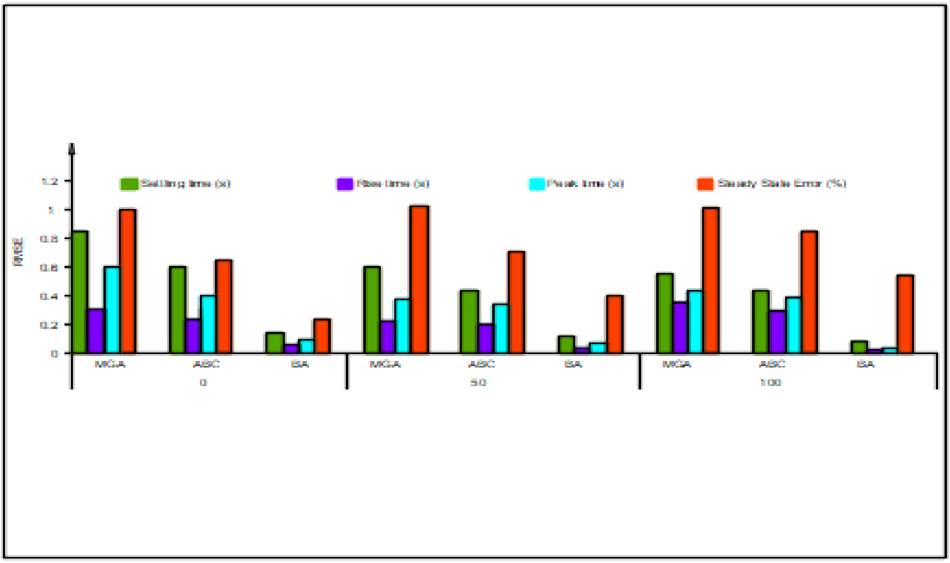


Fig 5; DC brushless electric motor drive[22][6]

Table 4. Metaheuristics and Evolutionary computing methods[10][22][1].

S/N	Year	Application	Technique
1	2016	Axial flux permanent magnet design	GA and analytical evaluation
2	2018	PID controller	BA
3	2018	Design of PMMs for EV	Adaptive DE with FE
4	2018	Optimum design of SPSRM	GA and DE

Table 4 gives comprehensive techniques and applications of metaheuristic and evolutionary approaches using the genetic algorithm, Bat algorithm, Differential evolution with finite elements, and genetic algorithm with differential evolution[23].

6. Genetic Algorithm, particle swamp, and Speed control Motor drives Efficiency.

Nonlinear optimization is required in solving can be solved in many areas of the power system, the analytical method has low dimensions and convergence, therefore genetic algorithm and particle swamp optimization techniques can be used to solve most of this problem GA and PSO have been used for a lot of motor drive techniques applications, especially in electric tractions[23][16]. An induction motor could be a highly efficient electrical machine when working closely to rated torque and speed, when it is at no load, there is no balance between the copper and the iron losses and therefore there is a reduction in efficiency[24][25]. Power factor and load efficiency can be highly improved through the adjustment of the motor excitation by the load and the speed, this can be achieved when the induction motor is fed through an inverter or could be redesigned with optimization algorithms, this represents the application of optimization technique of to effectively control three phase induction motor[26][27].

7. Multi-objective particle swamp algorithm.

the MOPSO was employed to achieve the goal of the optimal problem of the two objective functions such as maximization of the operating efficiency of the system drive for a given mechanical load and maximization of the equivalent power factor for the start-up of the induction motor and also steady operations[28][29][1], the optimization always ensures that the maximum allowable current constraints of the stator are not exceeded, the techniques always ensure that the flux level in any machine can be adjusted to give the required solution of the maximum efficiency and maximum power factor required for a given speed torque and load[30]. There is always a considerable level of efficiency and power factor improvement using MOPSO as compared to field-oriented control and constant voltage to frequency ratio-based control, for the operation to be optimal three objectives' functions were deliberately chosen such as to maximize motor power factor, to maximize efficiency, and to minimize the motor stator current[29]. The fig above shows the stator current, and power minimized simultaneously. The stator current is minimized using MOPSO this led to great efficiency compared to other strategies

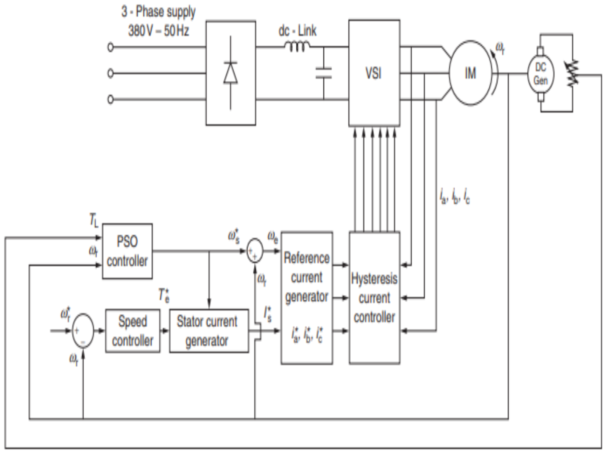


Fig 7. Drive system using PSO based on the loss model controller

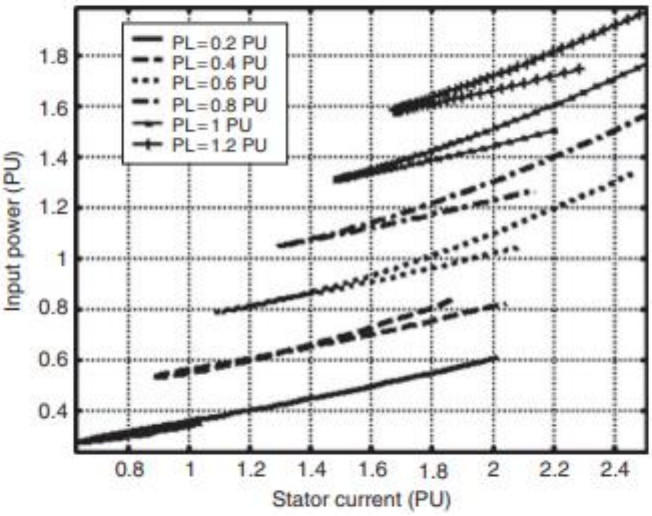
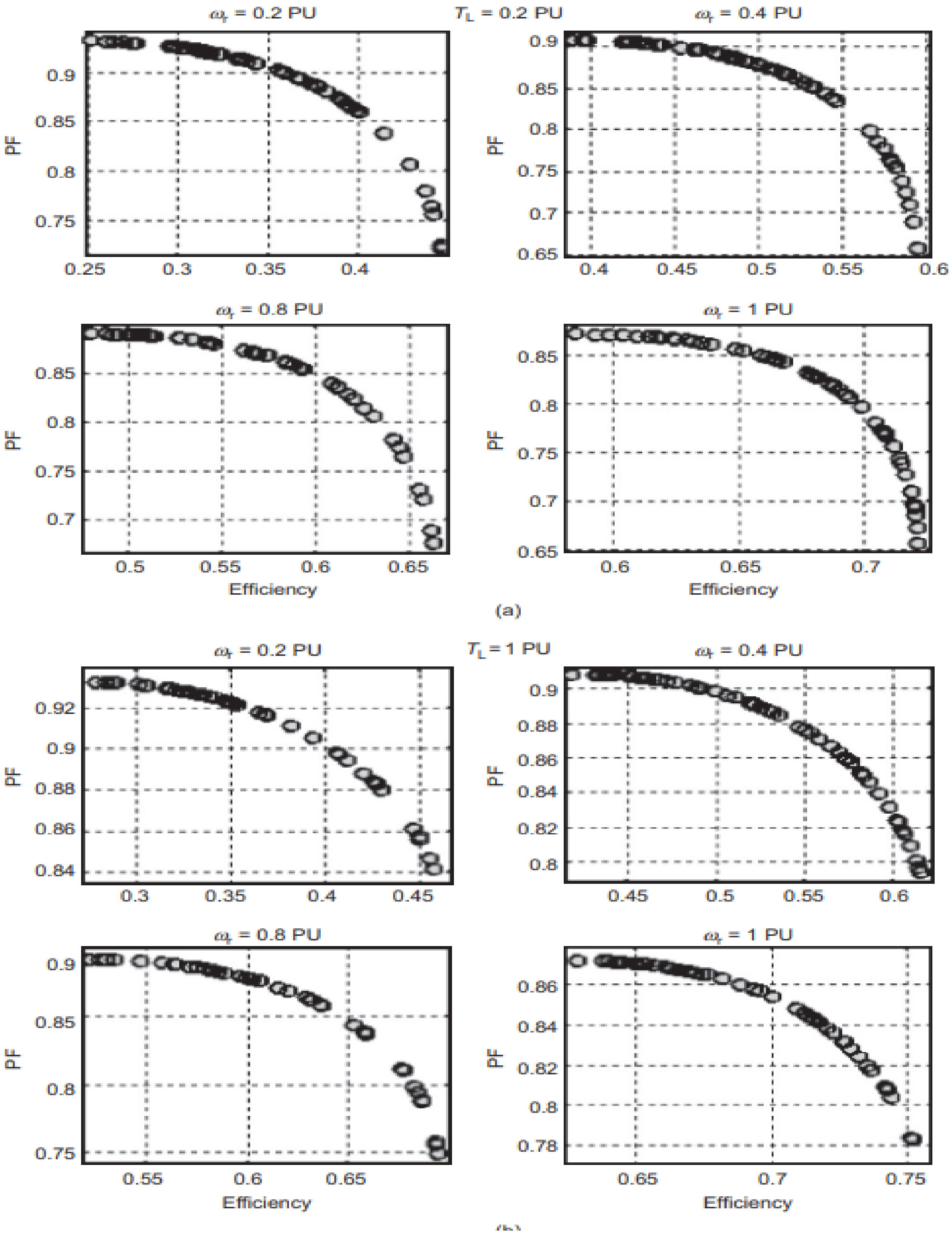


Fig 6. Input power versus stator current at various speeds and rated power[1]

The block diagram below shows the particle swamp optimization process, the PSO algorithm receives the rotor speed and a load of torque, and the PID countertrolled will always examine the frequency slip where the optimum fitness function occurs at the speed of the rotor and load torque, in the process ME and MPF problem was solved using MOPSO.



(a)

(b)

Fig 8. Pareto front of maximum efficiency and maximum power factor problem for different levels of rotor speed ωr = 0.2, 0.4, 0.8, 1 PU and different levels of load torque: (a) TL = 0.2 PU; (b) TL = 1 PU[1][28][30].

8. A Novel Self-Regulating Hybrid (PV–FC–Diesel–Battery) Electric Vehicle-EV Drive System.

This is a novel self-regulating tri-loop driven error controller of a hybrid PV-FC -diesel-battery powered all-wheel-drive electric vehicle using a four-wheel permanent Dc motor, this is modelled into nonlinearity in motor and also the viscous friction and load inertial, this is proposed to regulate current and motor speed and also to avoid inrush condition and overload also for motor dynamic reference speed tracking[32][33]. This scheme is used to ensure control loop coupling, grid interface stability, and dynamic energy efficiency while the reference speed tracking capability is maintained, a novel FACTS-based green filter compensator to stabilized motor drive scheme to ensure a stabilized DC minimal inrush current condition, damped load excursion and bus voltage[34][35]. There was a novel comparison between MOPSO and genetic algorithm MOGA optimization and online search techniques for dynamic turning of different controllers under varying renewable energy source conditions and load excursion, consequently, an electric vehicle is one of the proffers one of the solutions in the reduction of consumption of the fossil fuel and emission of pollution of gas from the greenhouse effects, but the purely electric vehicle has some limitations because of the sizes and vehicles habitations reduce its range[31][36]. Electric motors of several types could be used for EVs for propulsion such as DC and AC motors have widely found applications in this area, using permanent brushless dc motors and permanent synchronous motors,

Electric vehicle DC motor speeds control has been discovered using conventional PID, PI, fuzzy logic-based, nonlinear, model reference adaptive control, artificial neural network, adaptive variable structure, and feed-forward computer strategies among others, the need for tuneable control mechanism is needed for any nonlinear system without modelled dynamics. The GA and PSO algorithms for self-regulating are always utilized for tracking of reference under any varying parameters and load conditions to detect the motor minimum overcurrent, ripple condition, and inrush to enhance power utilization.

The fig below shows a four-wheel electric vehicle drive system with an FC source, diesel generator, and battery for backup, the DC compensator ensures efficient, stable, and minimal inrush operation of the hybrid scheme of renewable energy.

The PSO and GA coordinated controllers and self-turned regulators are used to achieve the following.

Diesel AC generator set with control regulator load dynamic and excess generation matching also to stabilize common DC collection using the six-pulse [37]controlled rectifier. The AC/DC power converter regulator is to regulate the DC voltage at the diesel AC/DC interface and always ensures limitation to inrush condition and dynamic power matching to minimize the current transient and boost the diesel utilization engine interface of the AC-DC bus. The PMDC motor drive with speed regulator ensures speed tracking reference with a minimum of inrush condition to reduce transient voltage and improve utilization of energy[38]. The DC side green plug filter compensator GPFC-SPWM regulator for pulse width switching is to regulate the voltage at the DC bus and reduces inrush transient current and excursion of load and nonlinear FC volt-ampere characteristics[39][40].

9. Electric motor types used in electric vehicles

The traction power required for an electric motor in electric vehicles is of different types this must be put into consideration when making the selections we have the DC series motor where the field winding is connected to the armature winding and it is the self-excited motor, it has mechanical commutation and brushes, it has the advantages of high starting torque and the problem of poor speed regulation and the motor is expected to be loaded before starting[23].

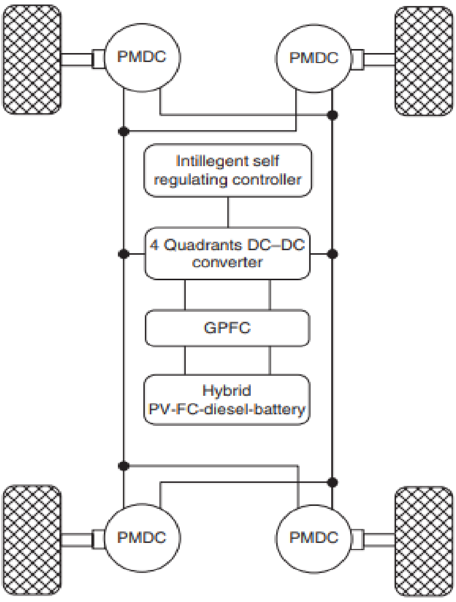


Fig 9. A prototype all-wheel-drive electric vehicle using four PMDC motors [40][23]

Permanent Magnet Motors: This is a synchronous motor in which the rotor rotates at the same speed as the stator, the field winding is replaced by a permanent magnet unlike the conventional motors the permanent magnet synchronous motor is also called permanent magnet AC motor, the permanent DC motor has electronic commutation, not mechanical commutation and is always powered by DC supply, they can be used in automobiles, computer drives, and toy industries. The three-phase induction motor works on the principle of electromagnetic induction as the changing magnetic field will always induce EMF in the conductor, they have high copper loss and speed control problems, but they are simple and robust and have the self-starting capacity[23][40].

Three-Phase Induction Motor: Induction motor is based on the principle of electromagnetic induction in which the conductors in the changing magnetic field induce an emf across the conductor [4]. Due to the interaction of stator and rotor flux, the motor rotates. The advantages of induction motors are simple in construction and are cheaper and maintenance-less [4]. And they can be operated in dirty environments like dust, the presence of water, and explosive areas due to the absence of brushes which will produce sparks. They are self-starting motors. The disadvantage is that the speed control is difficult. The motor operates under a lagging power factor hence some power factor correcting devices are required. They have a higher copper loss.

10. Conclusion

Motor drives take a significant amount of the global electricity used, and therefore their high demand for efficiency to satisfy the global demand and this can only be achieved by al-based soft computing technique, designed methodology, control system, and proactive techniques will always be required to get optimal performance of the electrical rotating machine. A wider range of computational intelligent techniques have been reviewed in this work considering their applications, strength, and the various limitations among different computational algorithms, combinations of different soft computing hybrid techniques have been observed, and how the system was greatly affected by them, different works have indicated how various metaheuristic modern and soft computing techniques led to increase in efficiency and output, especially in motor drives. The use of soft computing dynamic techniques such as PSO, GA, and controller of multiple objectives among others, is demonstrated using the main optimal application in the operation of motor drives, soft computing gives an advantage of achieving multiple and conflicting objective functions of tracking of effective speed reference, limiting of inrush current reduction of losses among others.

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