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Artificial Intelligence Based Speed Control of Induction Motor- A Detailed Study

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Abstract- ***This paper presents a novel speed vector control scheme of an induction motor (IM) based on robust adaptive variable structure control (VSC) law and its experimental validation are presented. The design of the speed controller greatly affects the performance and efficiency of an electric drive. The combination of non-adaptive variable structure control (VSC) law with the proportional integral (PI) speed controllers is used to control an induction machine. In this proposal in order to increase the efficiency and to provide high performance, PI controllers are replaced by the adaptive controllers. The mathematical model for the adaptive VSC based on genetic algorithm is presented. Root locus and pole assignment techniques are also proposed along with the transient response technique. The simulation and result of this experiment gives high performance dynamic characteristics, change of motor speed and external load disturbances. To provide a numerical comparison between the controllers, a performance based index speed error is assigned.***

Keywords: ***variable structure control, PI controllers, induction motor drive, genetic algorithm.***

I INTRODUCTION

A recent development in the theory of the vector control, fast digital processor and power devices provides the possibility of high performance induction motor drive control. Conventional PI controllers are designed based on classical theory. The inherent disadvantages of the PI controller have encouraged the replacement of the conventional controller with self-tuning Pi controllers. Fixed gain value PI controllers may not be usable to provide required control performances due to continuous variation in the plant parameters. To overcome this, a self-tuning PI controller should be used. A lot of techniques are proposed for tuning the PI controller parameters. The design of the self-tuning PI controller procedure consists of tuning their parameters in order to achieve required bandwidth and disturbance rejection. Due to the non-linearity control of the self-tuning PI controllers there occurs degradation in the drive performance. To avoid this artificial intelligence techniques such as neural network, variable structure control, fuzzy logic solutions are applied. The most significant property of a VSC is robustness, insensitivity to parameter variations, fast dynamic response.

This paper provides the speed control of the induction motor by using variable structure control technique (VSC) via genetic algorithm. In this genetic algorithm the speed signal of the induction motor is only required in control algorithm. The final view of simulation and the results of the VSC induction motor drive is proposed in this paper.

II SELF TUNING PI CONTROLLER

A self-tuning system is capable of optimizing its own internal running parameters in order to maximize or minimize the fulfillment of an objective function; typically the maximization of efficiency or error minimization. A self-tuning proportional-integral (PI) controller in which the controller gains are adapted using the particle swarm optimization (PSO) technique is proposed for a static synchronous compensator (STATCOM). Static synchronous compensator (STATCOM) is one of the typical facts devices which are used to improve the voltage profile and transient stability in power system by damaging the low frequency oscillation in it.

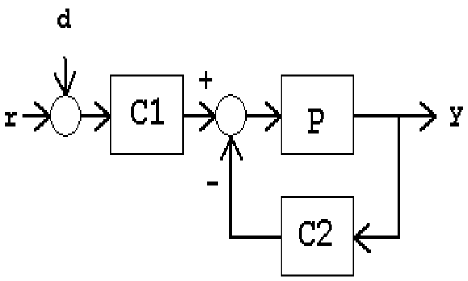

Fig: Self-tuning PI controller

$$C1 = (K_p\, Kz + Kp \frac{\Delta T}{T} \sum)$$

$$C2 = (K_p + Kp \frac{\Delta T}{T} \sum)$$

III STRUCTURE OF GENETIC ALGORITHM

GA is a global search optimization technique that is very much effective to solve optimization problems. Compared to other optimizing techniques, GA method is more superior in avoiding local minima which is a common aspect of the non-linear systems. It is a derivative free technique. It is more attractive to non-smoothy and noisy signals. The genetic algorithm technique has three main stages. They are as follows:

- ***Selection***
- ***Cross-over***
- ***Mutations***

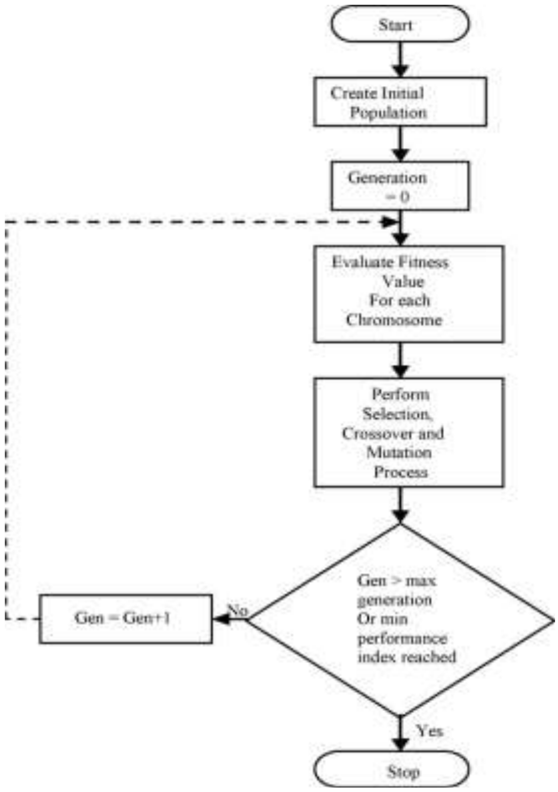

Fig: Structure of a genetic algorithm

Algorithm:

Step 1: start.

Step 2: create initial population.

Step 3: Initialization of the variable, generation=0;

Step 4: Evaluate fitness value for each chromosome.

Step 5: The next stage perform selection, crossover, and the mutation process.

Step 6: **T**he next step performs the conditional statement loop, with the condition [Gen>max].

Step 7: If the condition becomes true the loop will execute and the result will be provided.

Step 8: If the condition is False an feedback loop with condition Gen=Gen+1 will be executed

Step 9: Stop the program.

Selection: The purpose of this operation is to obtain a mating Pool with the fittest individuals selected according to a probabilistic rule that allows these individuals to be mated with the new population.

Crossover: In this stage the genetic crossover operation is applied between the parent pairs from the mating pool to generate new offspring. This operation can be one-point or double-point operation. This operation is performed with a crossover probability (P_c).

Mutations: The last operation is the genetic mutations which introduces the change in the offspring bit string to produce new chromosomes. This operation is performed with the mutation probability (P_m). This is also used to avoid the fall of the population into a local optimal point.

IV CONDITION FOR TERMINATION

- *A solution is found that satisfies minimum criteria*
- *Fixed number of generations reached*
- *The highest ranking solution's fitness is reaching or has reached a plateau such that successive iterations no longer produce better results.*
- *Manual inspection*
- *Combination of above.*

Genetic algorithm parameters

GA property	Value/method
Number of generations	10
Number of chromosomes in each generation	8
Number of genes in each chromosome	2
Chromosome length	40 bit
Selection method	Stochastic Universal Selection (SUS)
Crossover method	Double-point
Crossover probability	0.7
Mutation rate	0.05

V PI CONTROLLERS USING GA

The accuracy and effectiveness of genetic algorithm for selecting non-linear and multidimensional search space it can be applied for the tuning of a PI controller. The mathematical function derived from the genetic algorithm for the PI speed controller is given as the reciprocal of integral with time of absolute error (ITAE). The mathematical cost function is given as:

$$ITAE = \int_0^t t|e(t)|dt$$

During the search process the genetic algorithm looks for optimal setting of PI speed controller such that the cost function can be considerably reduced.

VI FUZZY LOGIC IN PI CONTROLLERS

The speed controlling operation of a PI controller by using online genetic algorithm cannot be much effective and attractive because of its inability to cope with the online changes in the system parameters gains as well as disturbance rejection. Even though genetic algorithm is being proposed for the PI controllers, for online strategies it requires high processing speed and power. Hence this will create problems in the real time application purposes. Hence we found the remedy for this problem that is the fuzzy logic controller. The main advantages of the fuzzy logic is, it can applied to a time varying, non-linear, structure varying tuning operations of a PI controller.

The design of the fuzzy logic controller is simple and it can be easily implemented. The FLC is widely used in the industrial control systems. The FLC based self-tuning PI controller circuit is given as:

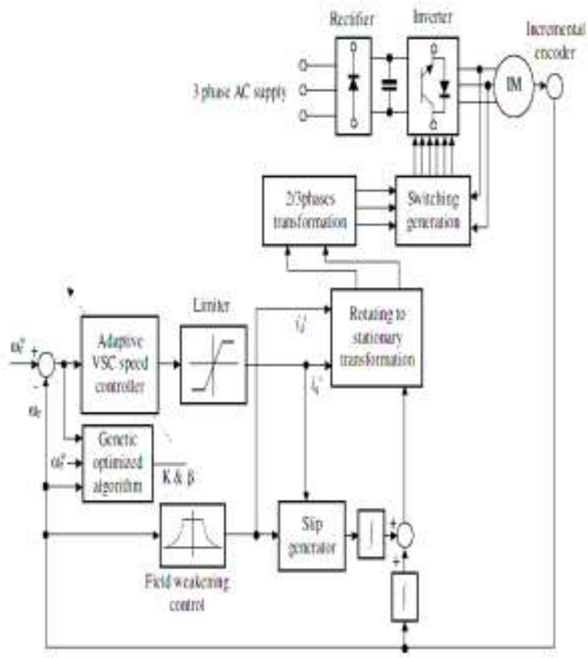

Fig: FLC based self-tuning PI controllers

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1. Speed Controllers using Fuzzy Logic:

FLC is able to handle the nonlinearities, load disturbances and the uncertainties of the Direct Torque Control it has also been used to entirely replace the traditional PI controller. In FLC speed controller, the inputs are normalized values of the speed error and the rate of change remain between ±1 limits of speed error. Two scaling factors (*K*e and *K*d) are used.

*K*e= actual speed error.
*K*d= Rate of change of actual speed error.

The output of the controller is the normalized change of the motor torque command which when multiplied by a third scaling factor (*K*u) generates the actual value of the rate of change of the motor torque demand.

Note: The following fuzzy sets are to be used

NB=NEGATIVE BIG, NM=NEGATIVE MEDUIM,
NS =NEGATIVE SMALL, EZ = ZERO,
PS = POSITIVE SMALL, PM= POSITIVE MEDUIM, PB = POSITIVE BIG

2. Fuzzy Sliding mode Controller:

Fuzzy sliding mode controller is a variable structure control strategy with high frequency switched feedback control which forces the state of the system to slide on a predefined hyper surface. The discontinuous control action switches between these several functions according to plant state value at each instant to achieve the desired trajectory. SMC is known for its capability to cope with bounded disturbances as well as model imprecision which makes it ideal for the robust nonlinear control of induction motor drives. Designing a sliding mode speed controller for the induction motor DTC drive
Starts by defining the speed error.

Another approach to reduce the chattering phenomenon is to combine a FLC with a SMC. Hence a new fuzzy sliding mode controller (FSMC) is formed with the robustness of the SMC and the smoothness of a FLC. In this technique the term $-k1\text{sat}(s)$ is replaced by a fuzzy inference system in order to smooth the control action. The choice is crucial; small values may not solve the chattering problem and large values may increase the steady state error, requiring a compromise choice when selecting the boundary layer thickness.

The introduction of the saturation function represents the continuous approximation of the discrete relay action by the sign function. The system robustness becomes highly dependent on the boundary layer thickness

VII RESULTS

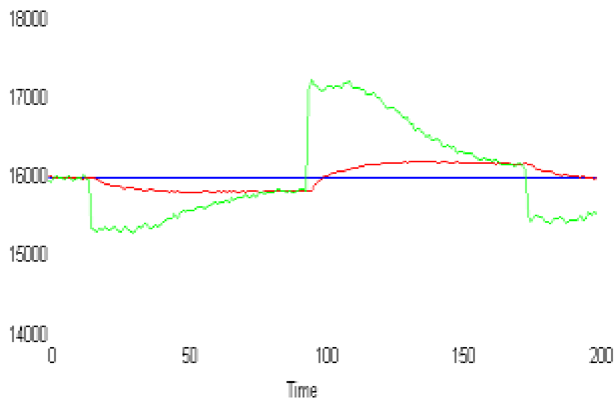

Fig: PI controller befor self tuning

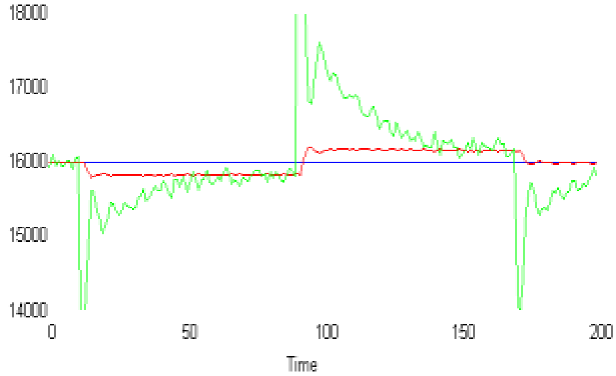

Fig: PI controller after self-tuning

The simulations values are invaluable while implementing the results in IM without the required motor conditions. The motor is started under 25% rated load with a speed command of 50 electrical rad/s and is running under normal operating condition from t=0-0.5 s. The effect of parameter variation on the performance of the different controllers, a 20% step increase in the motor stator resistance is applied at t = 0.5 s. The simulation is performed for the four different speed controller strategies.

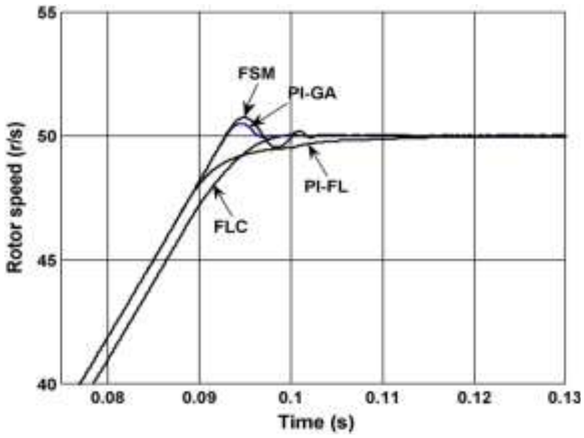

Fig: Starting transient response of IM

1). PI-GA 2). PI-FL 3). FLC 4). FSM

Speed Response Characteristics curves:

The FLC has the best transient response where the motor speed is approximately built up in less than 0.1 s without overshoot. PI-FL has an over damped response where the motor speed builds in 0.115 s without overshoot. PI-GA and FSM have a speed overshoot of 1% and 1.4%, respectively, which are still very small values. Both PI-GA and FSM show more robustness against stator resistance variation compared to FLC and PI-FL. When the 100% load change is applied to the motor, the rotor speed with the PI-GA strategy drops to 49.92 rad/s with a steady state error of 0.16%.

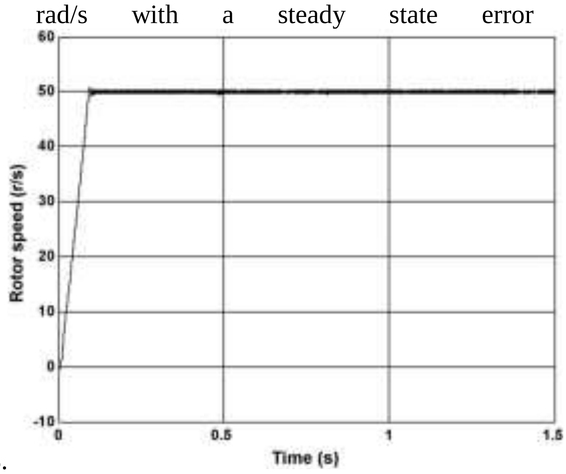

Fig: Speed response- Conventional sliding controller

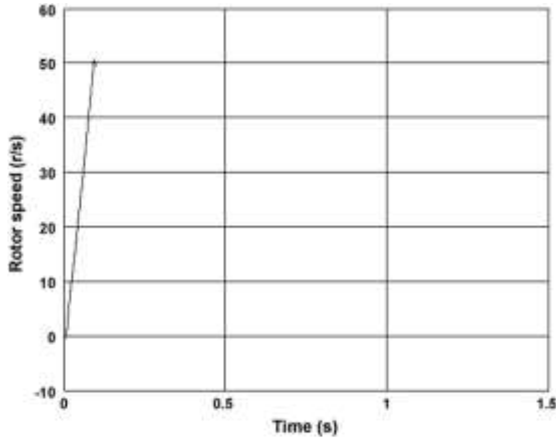

Fig: Speed response- Fuzzy Sliding Controller

IX COMPARISON

Method	PI-GA	PI-FL	FLC	FSM
1).Starting transient performance	good	good	Very good	good
2).Robustness	Very good	Very good	Good	Excellent
3).Disturbance rejection	poor	good	Very good	Excellent
4).Steady-state performance	poor	Very good	medium	good
5).computation effort	High at tuning	high	High	low

PI-GA works well under normal operating conditions, giving small drift but has a low torque disturbance rejection capability due to the fixed gain controller. Generally the GA off-line tuning process is simple but may need a lot of time to converge to the optimal solution, depending on the complexity of the drive system and as the choice of the GA parameters. PI-FL performs better than fixed gain PI-GA during a load torque disturbance. Compared to FLC, PIFL has better robustness against motor parameter variation as well as better steady state performance since the gain updating stops after a given limit of speed accuracy. PI-FL also has better steady-state performance compared to FSM which is affected by the chattering in the steady state. FLC has a better disturbance rejection capability compared to PI-FL and a better transient response during starting.

X CONCLUSION

In this fuzzy control of Induction Motor- four design strategies for the speed controller in Direct Torque Control of IM are proposed: PI controller tuned by a genetic algorithm and fuzzy logic, fuzzy sliding mode and fuzzy logic controllers. These design techniques are based on artificial intelligence techniques which do not require any mathematical modelling. All these techniques work well under normal operating conditions. Adaptive structure controllers show more robustness against motor parameter variations as well as high disturbance rejection capability compared to fixed structure techniques. The fuzzy logic speed controller needs some modifications to improve its steady state performance. The fuzzy sliding mode controller seems the best choice for the controller design in terms of robustness and disturbance rejection capability, but still needs modifications to reduce the chattering phenomenon in the steady state.

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