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Neuro-Fuzzy Controller of a Sensorless PM Motor Drive for Washing Machines

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Outline:

- Objective.
- PM Drive Systems; an introduction.
- Washing Machine Trends.
- Control Requirements.
- Neuro-Fuzzy Controller Design.
- Real-Time Implementation.
- Results and Discussion.
- Conclusions.

Objective:

- Design of a direct drive washing machine utilizing PM motor.

- The drive system consists of two sections;

- An implicit rotor position detection.
- PM motor control using a neuro-fuzzy approach.

- The results demonstrate the capability of such a drive system in applications where simplicity, reliability and stability are more important issues.

With recent developments in magnet materials, there is increasing acceptance of PMSMs in variable speed drives

A fast dynamic response and accurate performance can be obtained now by optimal combination of PMMs and MP control.

AC motor drive is a nonlinear multivariable system and has complex dynamic performance. When such a machine is used in RT systems, it calls for complex control strategies which would be difficult to implement.

In some applications speed control scheme is required, in other applications the position control is of greater importance. In some cases, the steady state operation is important, and in other cases the dynamic performance is more significant.

Modes of operation:

- Open-loop mode: oscillator controls the motor.
- Closed-loop mode: inverter power switches are controlled directly from the rotor position sensor.

The self-commutating DC motor drive have many of the desirable performance characteristics of both the DC and AC motors. In the self-commutating DC drive system, a rotor position sensor is essential for controlling the power devices of the inverter.

The main problem with present rotor position detection methods is cost and reliability.

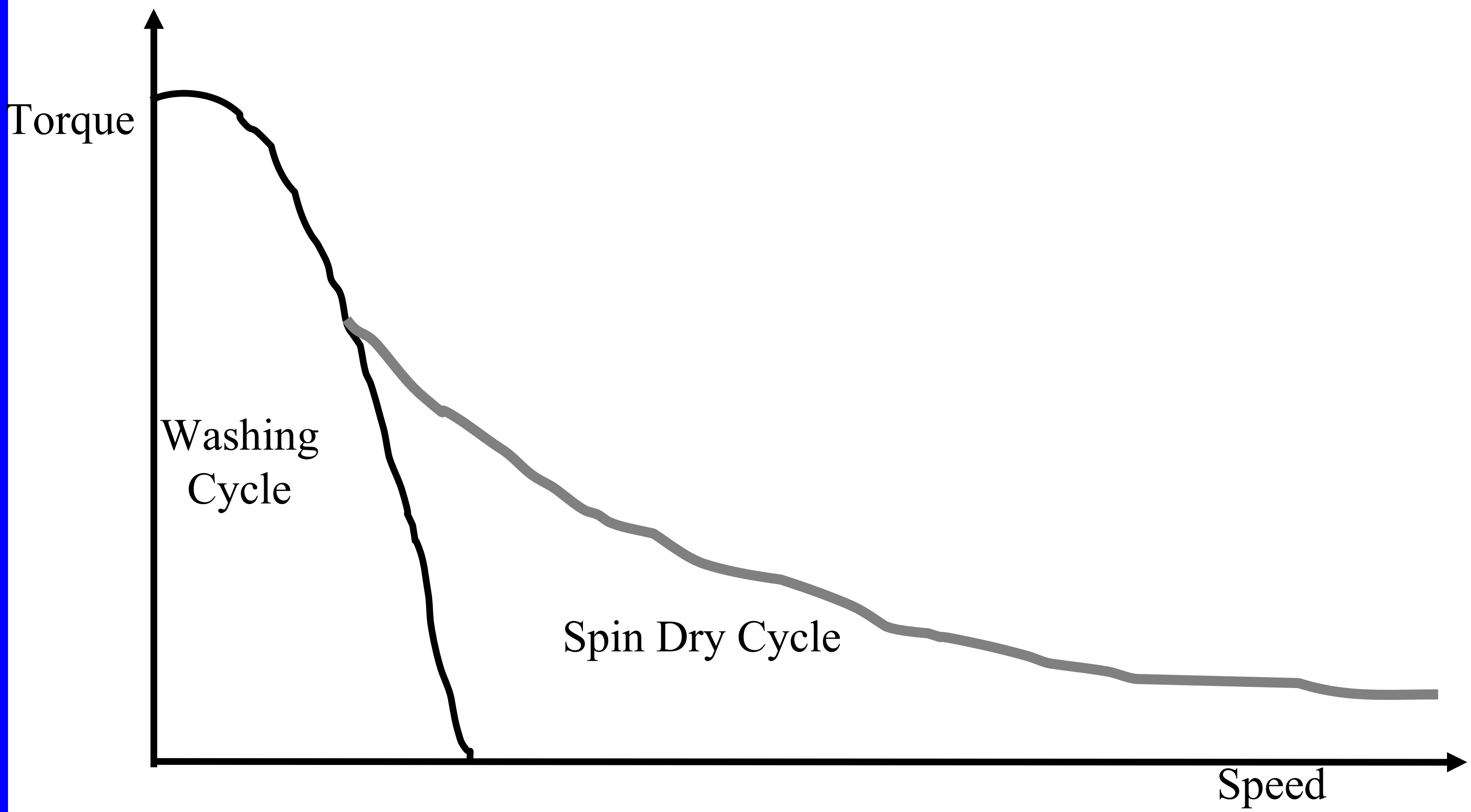
Washing Machine Trends:

- Washers have historically relied on induction motors and gearboxes. Such setups did not provide the kind of performance energy-efficient washes need.
- In the past, washing machine designs employed either a two-speed single-phase induction motor with electromechanical controls or a universal brushed motor with triac-switch-phase control
- One trend in washing machine design is to replace the machine's traditional drive system with an electronically controlled brushless alternative . *PM motors become more attractive than induction motors.*

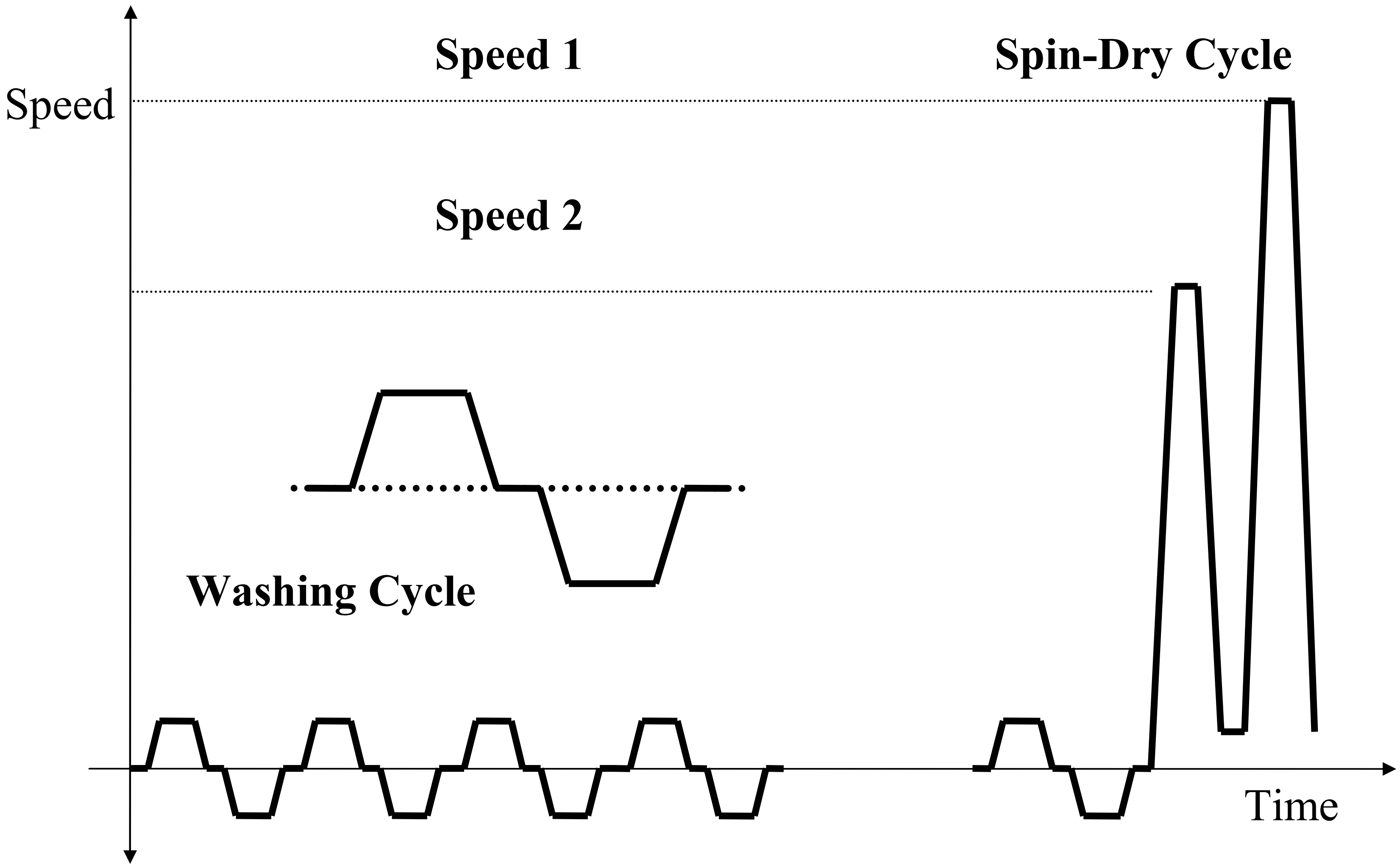
Washing Machine Trends:

- Another trend in washing machine design is the migration from vertical-axis to horizontal-axis washers to save water and energy
- Horizontal-axis washers require fast torque response from the controller to manage load conditions that are constantly changing. Higher spinning speeds require better balancing of the drum to prevent machine vibration.
- The control task requires high torque at low speeds and low torque at high speeds. *High amount of torque is required to perform the washing cycle. Higher spinning speeds lead to greater centrifugal force resulting in better water extraction, shorter spinning cycles, and shorter drying times.*

Typical torque-speed C/Cs



Cycles of Washing m/c Drives



PM MOTOR CONTROL REQURIEMENTS:

The motor speed (W) is directly proportional to the inverter output frequency (F);

$$W \,\alpha\, F$$

When the frequency (F) is variable, a constant rms value of the phase voltage (V) will make the amplitude of resultant flux (Φ) variable

$$V \,\alpha\, F^* \Phi$$

If F decreases with constant V, the Φ increases, therefore, in order to avoid magnetic saturation, it is essential to keep (Vi/Fi) constant.

- It is clear that increasing the supply frequency to increase the speed requires increasing the inverter output voltages in order to achieve constant resultant flux.

- Now, in order to run the PM motor efficiently, it is important to synchronize the frequency of the applied voltage to the rotor position of the PM rotor.

- An efficient control scheme is required to run the PM motor in sensorless drive.
- In this case, a neuro-fuzzy controller is proposed to satisfy the washing and drying cycles of the washing machine.

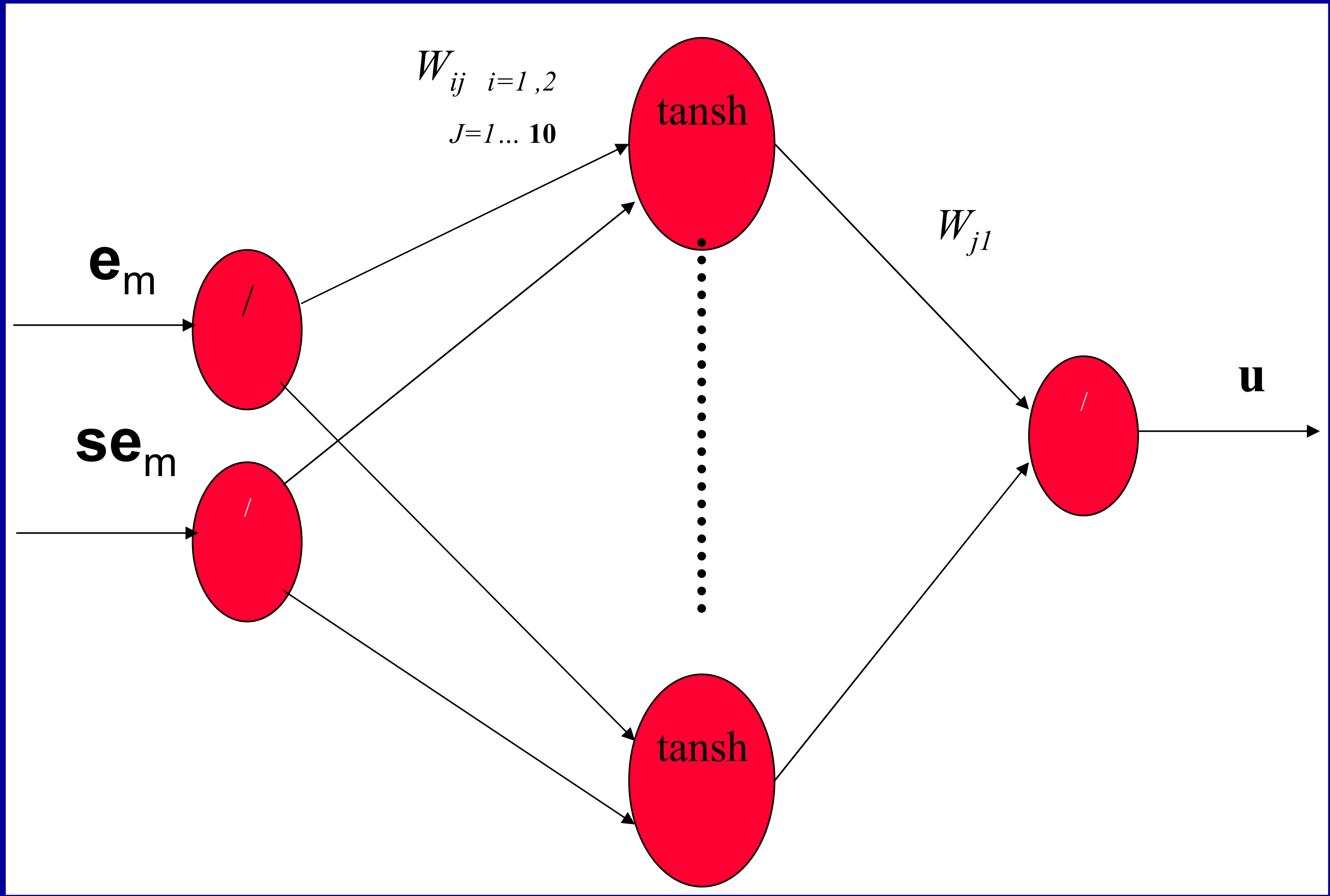
NEURO-FUZZY CONTROLLER

- A fast dynamic response and accurate steady state performance can be obtained for such applications by the combination of fuzzy logic and neural networks.

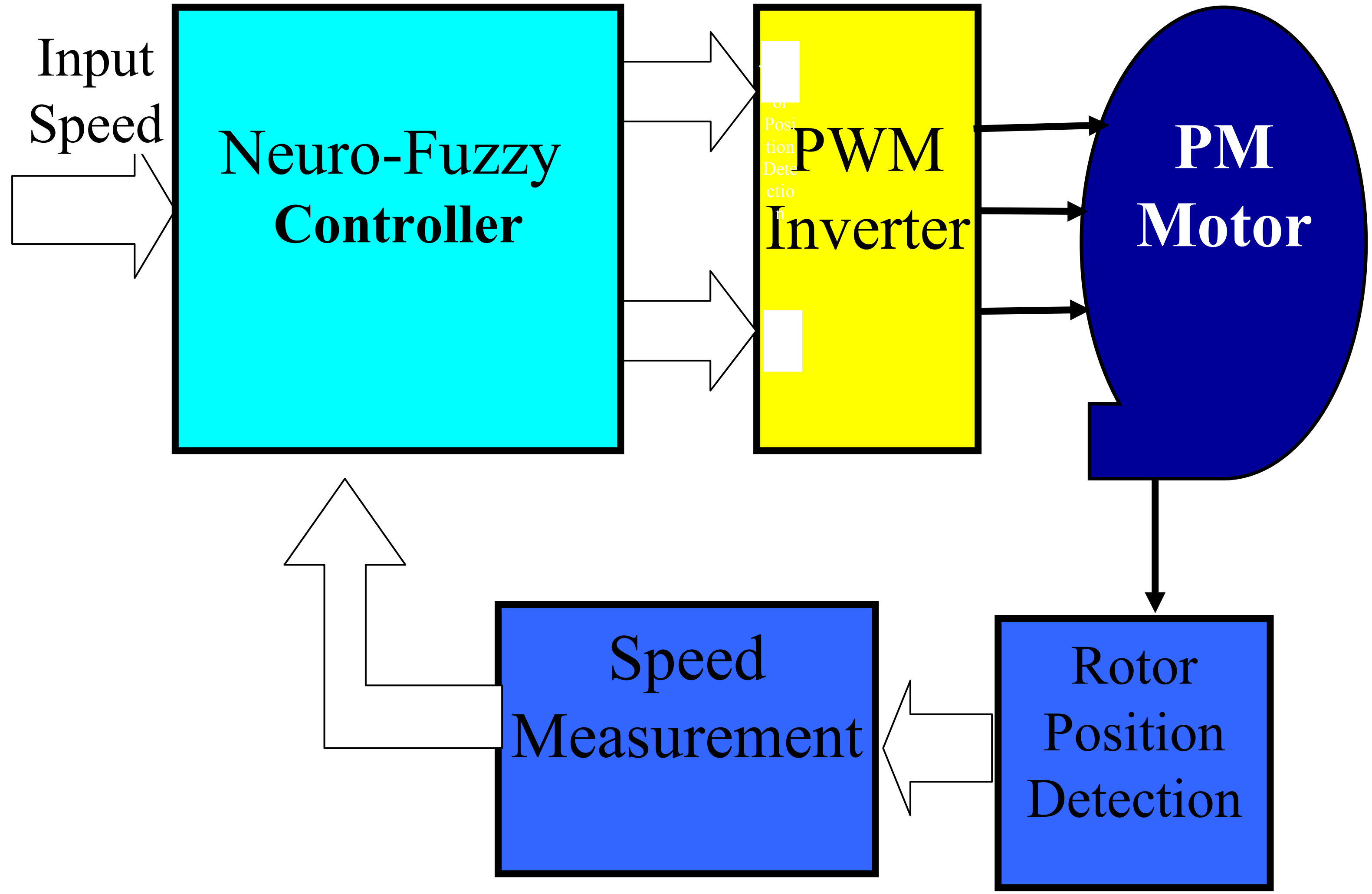
- The functional neuro-fuzzy controller will be formed by training a back-propagation neural net on the bases of fuzzy number rules described by their central values which are extracted using clustering algorithm from the available I/O collected from other control strategies.

- The NN needs 5620 iterations to learn the given input pattern, with learning rate of 0.1.

Neuro-fuzzy Controller



DRIVE SYSTEM COMPONENTS:



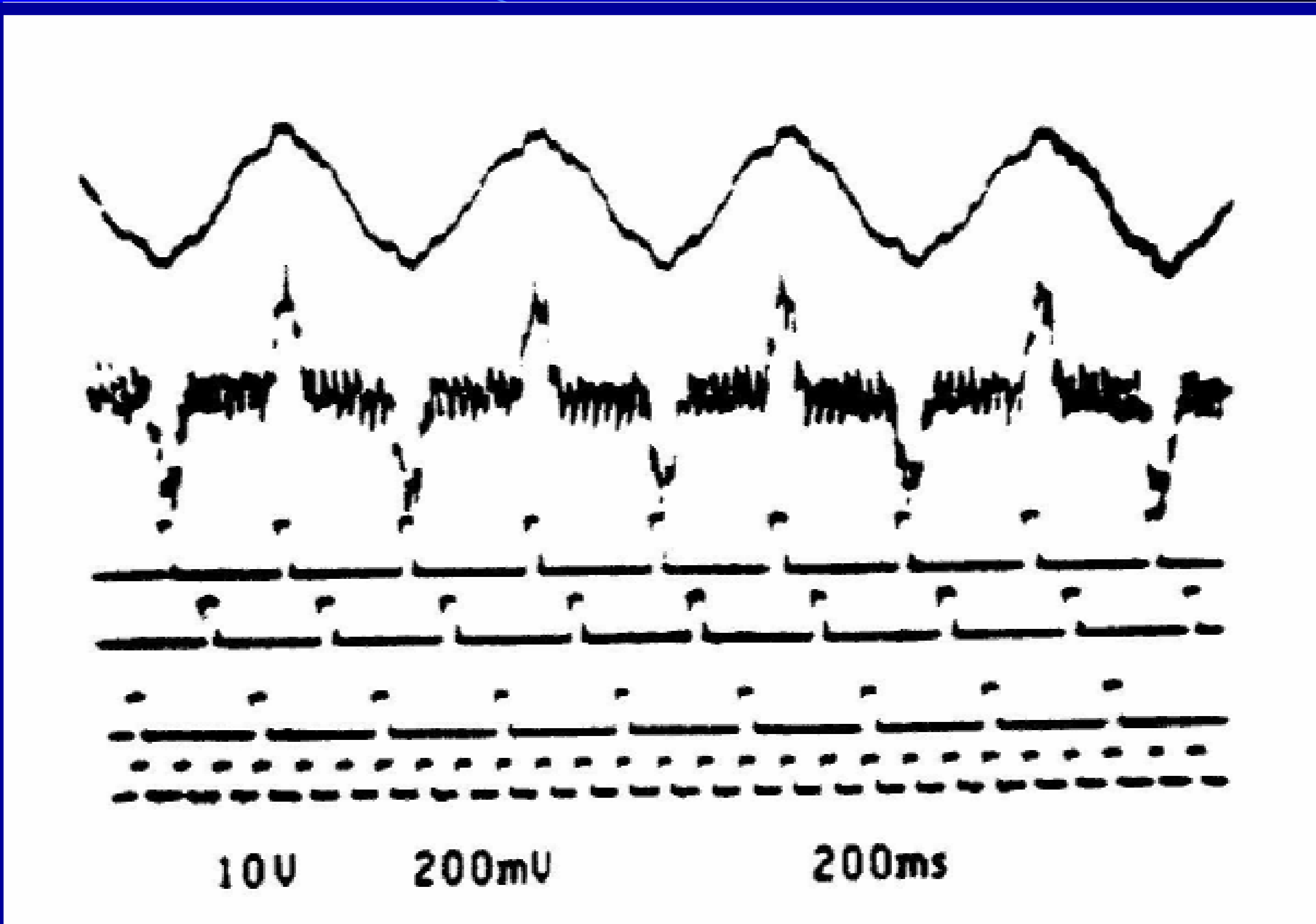
Rotor Position Detection:

An implicit sensor has been used for position, speed and load angle measurement.

Three rotor position detection units are used to produce 24 pulses each revolution.
Each detection unit consists of three groups of single turn search coils inserted into the machine stator.

The rotor position sensor output is used to cause an interrupt signal to the microprocessor. All the real-time tasks depend on this interrupt signal.

Rotor Position Detection:



Speed Measurement:

Calculate the time between each consecutive pulses coming from the rotor position sensor.
This is done by counting the number of pulses (C) coming from an external oscillator (Fp);

$$W = 2.5\ Fp/C \qquad (rpm)$$

The Fp is made proportional to the measured speed (W).

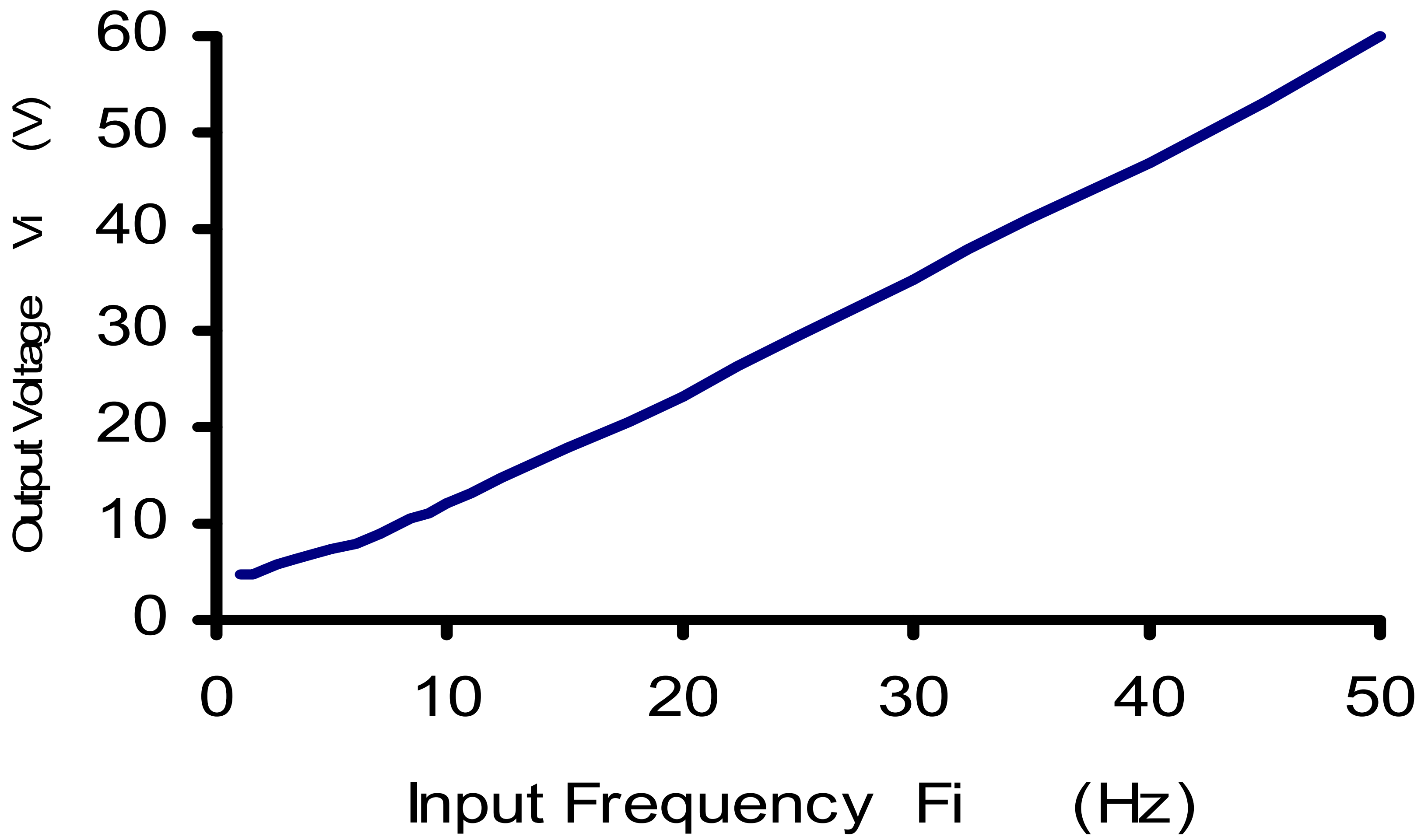
PWM Inverter:

- The PWM inverter has two control signals; the motor voltage, and the motor frequency.

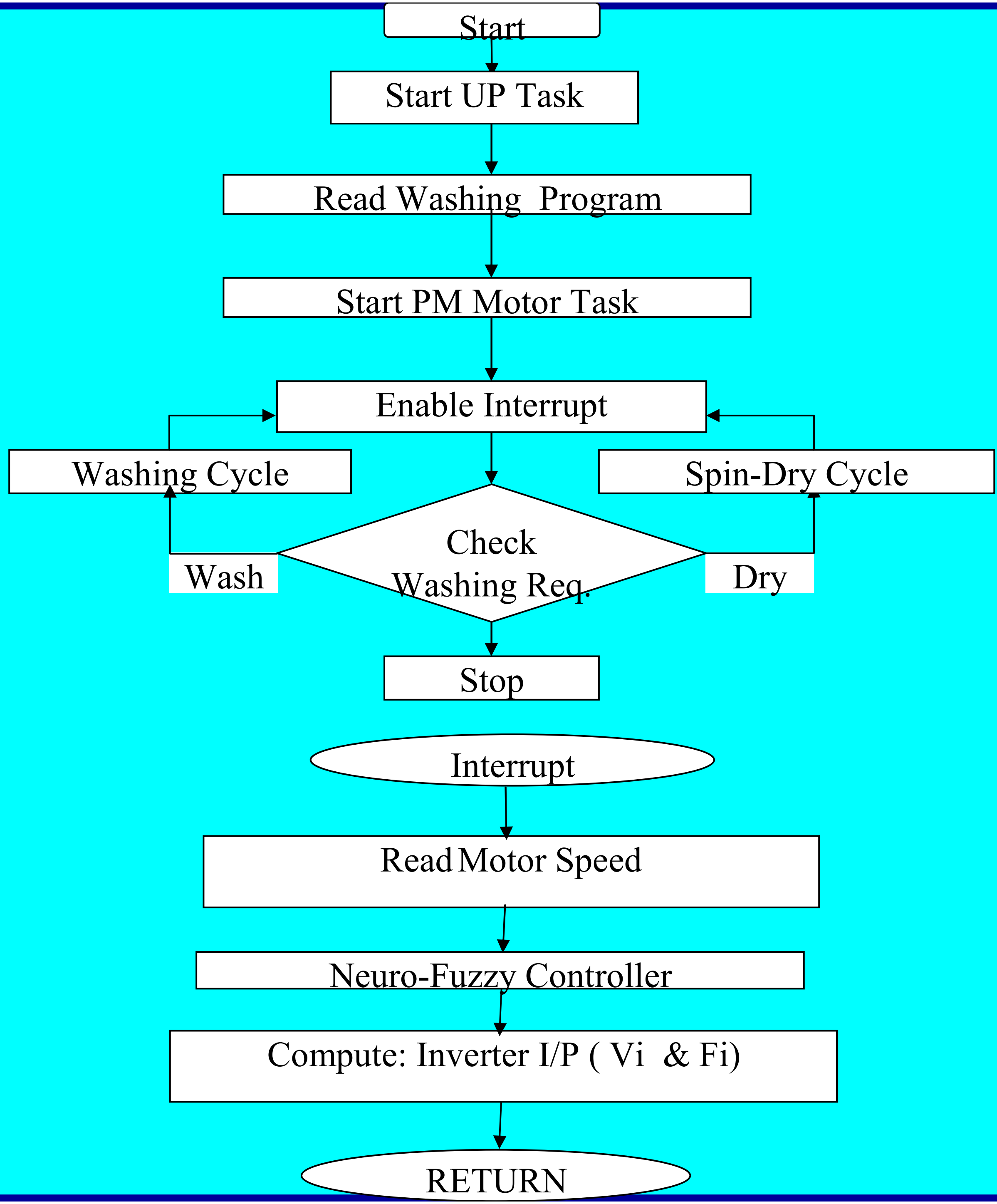
- The input frequency command is proportional to the required speed. The input voltage command is generated from the neuro-fuzzy controller .

- The inverter control logic calculates the duty cycle timing of the power switches to control the sinusoidal voltage applied to each phase of the motor.

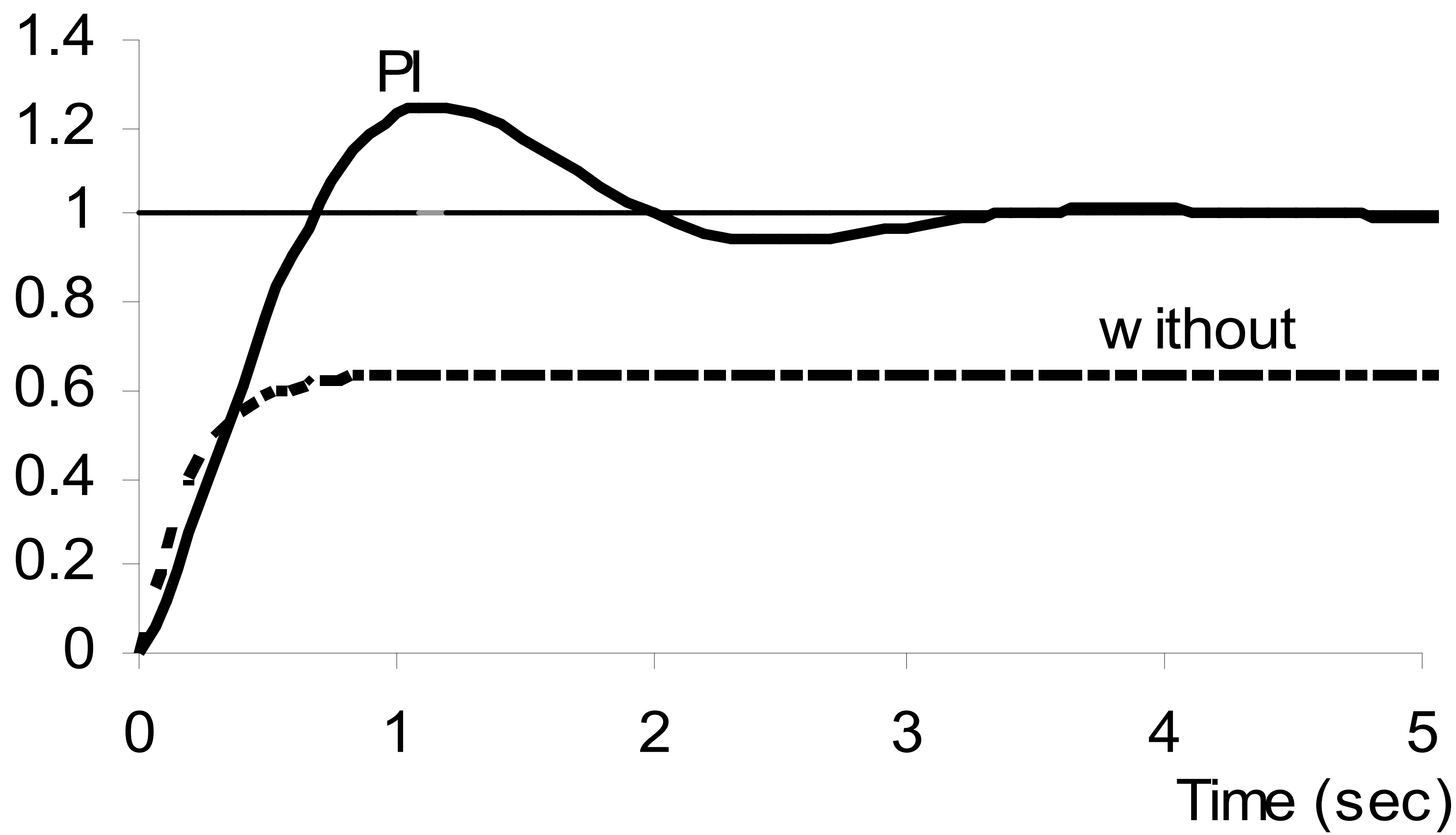
Voltage/Frequency curve of the PM Motor :



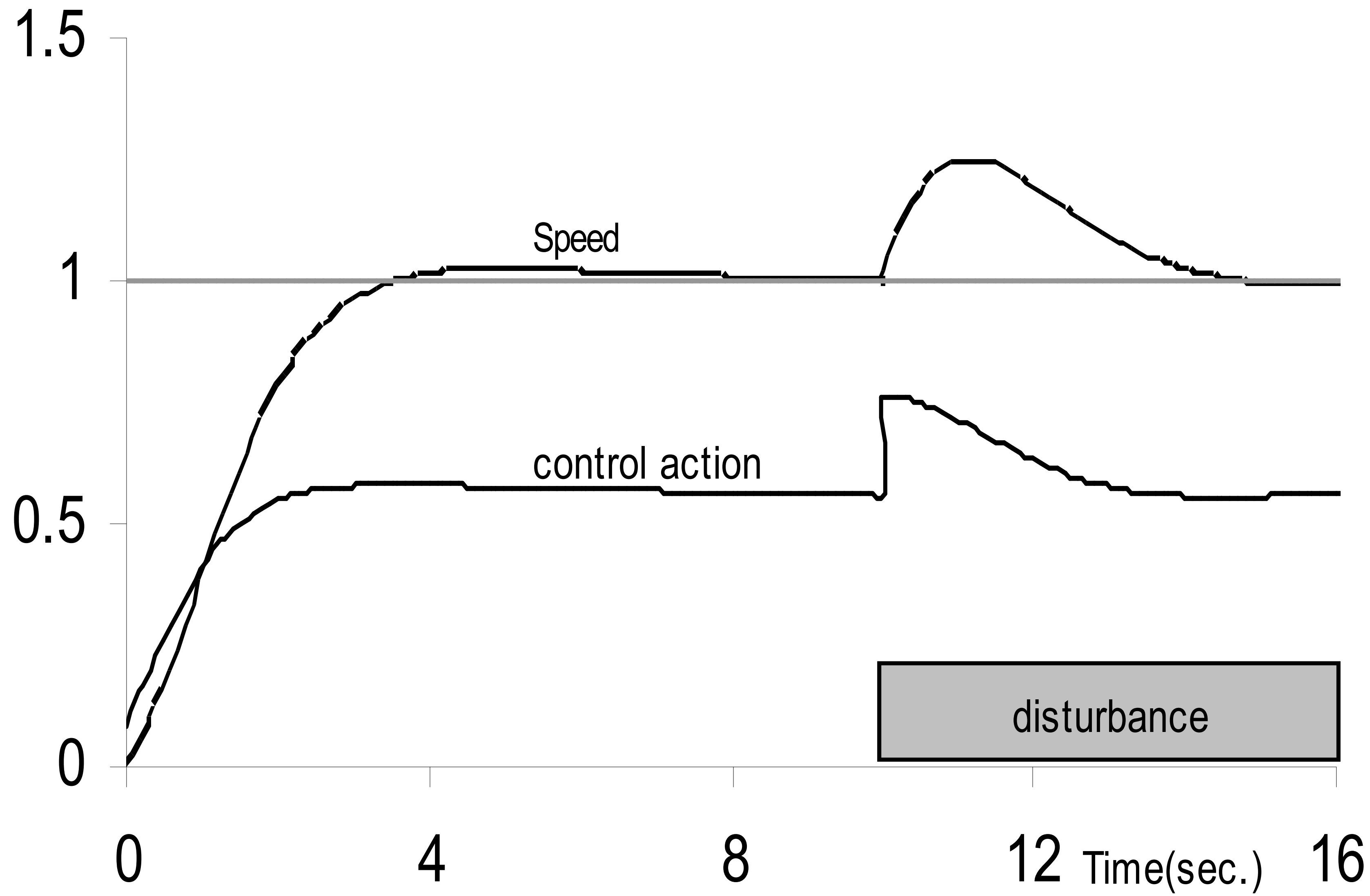
SOFTWARE DESIGN:



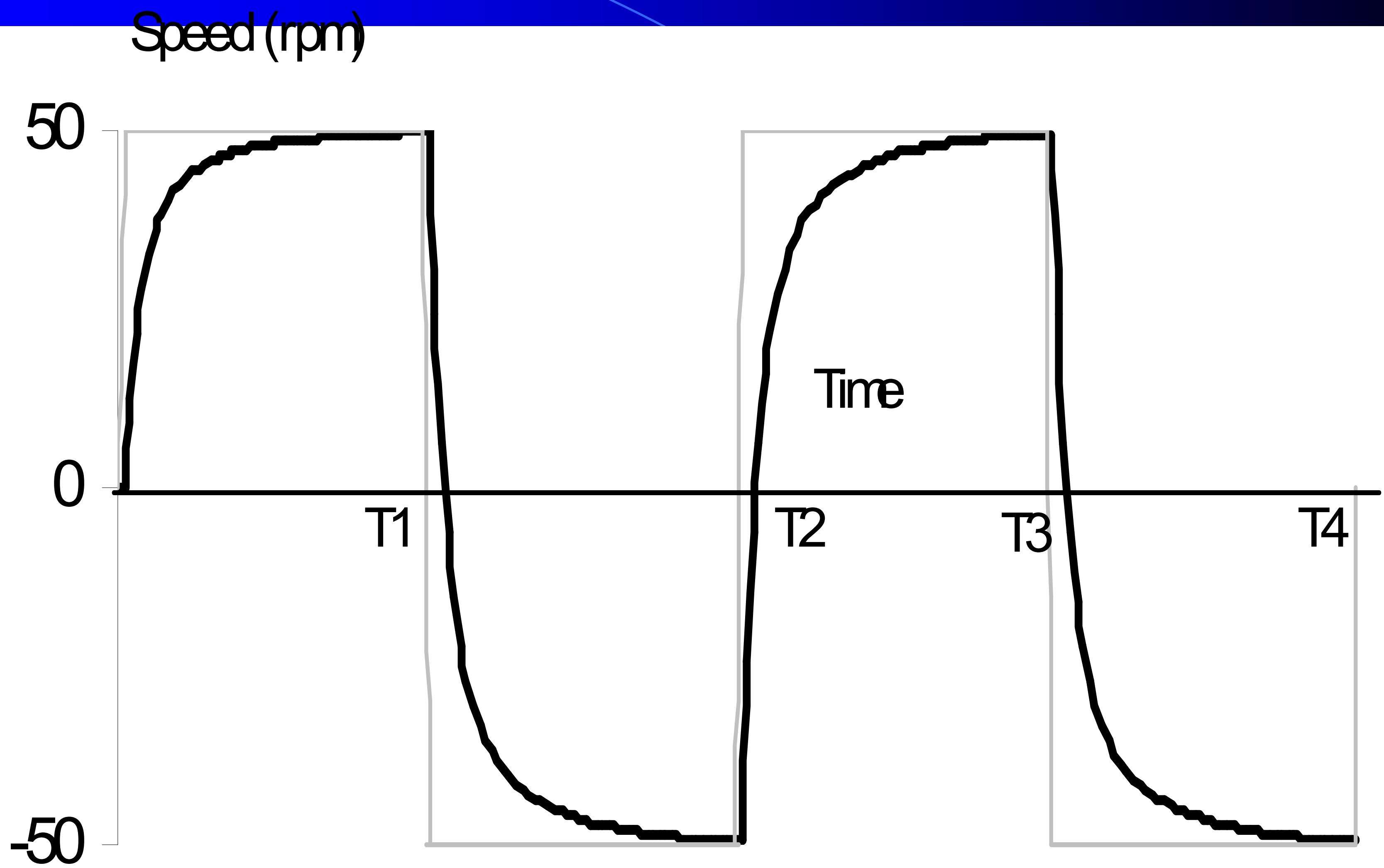
Speed response of the PM motor:



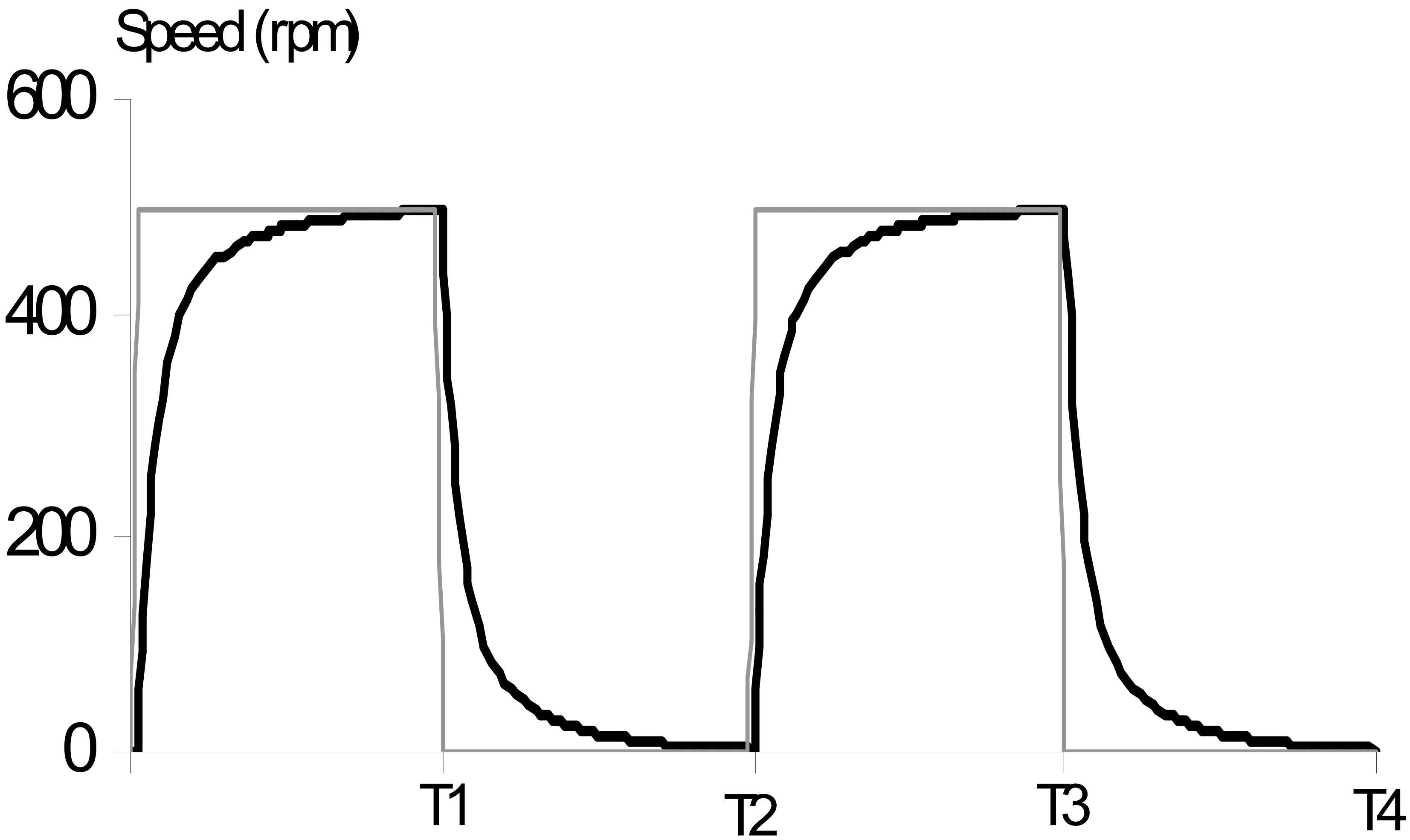
Speed response with disturbance:



Transient response during washing cycles:



Transient response during drying cycles:



CONCLUSIONS:

- The overall system presented in this paper is a sensorless PM drive system, since there is no need for any mechanical sensor.
- The rotor position pulses derived from the implicit sensor (search coils) are used for position and speed measurements.
- The PM synchronous motor is the most cost-effective and best choice for washing machine operation.

- A simple neuro-fuzzy control algorithm has been used to drive the power switches of the PWM inverter according to the washing program.
- This drive system is particularly suitable for washing machine applications where simplicity, reliability and stability are more important issues.

Thank You