CHAPTER 1

INTRODUCTION

The speed of a single-phase motor is a highly critical parameter. The speed is typically affected by loads placed on the motor. In this work, a FPAA based fuzzy logic controller (FLFC) is presented for controlling the speed of a motor. The FLC has an embedded neuro observer to estimate the speed in the event of feedback sensor failure. The FLC with the embedded observer help in appropriately altering the guidance laws that characterize the system behavior in the event of sensor failure. The structure of the resulting neural network based process model may be considered generic, in the sense, that, little prior process knowledge alone is required. The knowledge about the plant dynamics and mapping characteristics are implicitly stored within the network. In the present work, signals are processed in real time and combined with previous monitoring data to estimate, using the neural network, the process variable speed in the nonlinear system.

1.1 PROBLEM STATEMENT AND PROPOSED SOLUTION

The speed of a rotating machine is a highly critical parameter. For example, under armature voltage control and with constant field current, the speed will be proportional to the armature voltage. Constant power operation require armature current that increases inversely with speed, while constant torque operation will require constant armature current. On the contrary, with constant terminal voltage and speed control obtained by field current control, the field current (and hence the field flux) will be inversely proportional to the speed. Thus constant power operation demand constant armature current. Constant torque operation will require that the armature current variation be proportional to the motor speed [67].
[69]. Also, the speed is typically affected by loads and nonlinear variation of circuit elements placed on the machine (in addition to the type of control employed). For example, the inductance of the set of poles shall exhibit a nonlinear behavior in most of the machines and makes the control difficult. For example, when the rotor is aligned with any given pole pair, it is clearly mid-way between the other two pole pairs. Thus rotation in one direction will increase the inductance of one set of poles and decrease the inductance of the remaining set. Thus, if the information pertaining to the unknown features of the plant or its environment is acquired during operation, then the obtained information can be used for future estimation, recognition, classification and control or decision and the overall system performance is improved [70] [20]. Once it's complete, the control system can compensate for large number of changes in the plant and its environmental conditions.

In this context, the Field Programmable Analog Array (FPAA) is a recently evolved reconfigurable programmable analog module and allows the creation of dynamically reconfigurable analogue circuits. The FPAA based controller with a variable control law can be used to learn the unknown information during operation, and this information, in turn, is used as an experience for future decision and controls.

In the first phase of this work, a FPAA based variable control law controller is presented for controlling the speed of a machine. The proposed controller has an embedded variable control law functional block. The FPAA with the variable control law help in appropriately altering the guidance laws that characterize the system behavior in the event of system trying to track rapid changes in set point. The proposed FPAA assisted Controller is implemented as a generic module and structure independent and aims at maintaining the system response close to set
value even in constrained situations and for different optimal control conditions. The FPAA allows fine tuning of a lot of adaptive circuits.

In the second phase of the work, a neuro observer is embedded to estimate the speed in the event of feedback sensor failure. The FPAA tuned controller with the embedded observer help in appropriately altering the guidance laws that characterize the system behavior in the event of sensor failure. The structure of the resulting neural network based process model may be considered generic, in the sense, that, little prior process knowledge alone is required. The knowledge about the plant dynamics and mapping characteristics are implicitly stored within the network. The nonlinear functional mapping properties of neural networks are central to their use in control applications [17]. In the present work, signals are processed in real time and combined with previous monitoring data to estimate, using the neural network, the process variable speed in the nonlinear system.

1.2 BENEFITS OF THE PROPOSED RESEARCH WORK

The presented research work has the following advantages compared to conventional methods:

(i) FPAA is best applied to nonlinear, time-variant and ill-defined systems and in system control, the approach has a distinct edge over conventional methods.

(ii) “Preprocessing” large values into a small number of membership grades reduces the number of values that a controller has to contend with to make a decision.

(iii) By using a variable control law embedded into an FPAA based architecture more variables can be indirectly evaluated than a conventional PID controller.
(iv) Implementing a control system with FPAA logic can reduce design complexity to a point where previously insolvable problems can now be solved.

(v) The FPAA based control solution is ideal for low to medium complexity analog signal processing.

(vi) Also, when the same type of signal processing needs to be implemented across a range of systems, the reconfigurability inherent to the FPAA, (exploited in this work to implement the optimal control laws) allows the designer to easily and precisely implement the changes to tune the circuit for each system. With a programmable and reconfigurable approach, these changes in the operating conditions can be easily accounted [15].

(vii) The programmable gain stage as well as the programmable voltage reference proposed in this research, allows the designer to adjust the circuit to account for these changes in the operating characteristics.

1.3 USES AND APPLICATIONS OF FPAA

(i) Anadigm FPAA tool (provided along with Anadigm Designer®2) can be used to design complex analog functions. Using this tool, the designer can set the frequency and time domain specifications and obtain a variable transfer function.

(ii) The designer can directly import the design into Anadigm Designer®2 from where it can be downloaded to FPAA.

(iii) Closed loop control system analysis can be done.

(iv) Conventional PID controller can be implemented using the Anadigm PID tool of Anadigm Designer®2. This helps the designer to design complex P or PI or PD or PID controllers. This tool also shows the block diagram of the PID controller that has been designed along with
its mathematical model. In this the designer is allowed to change the proportional constant, integration and differentiation constant dynamically.

(viii) Sensor signal conditioning can be performed and this includes Gain, offset correction, linearization, etc.

1.4 IMPORTANCE OF FPAA

FPAA allows fine tuning of a lot of adaptive circuits. The FPAA based circuit can be regarded as a universal analogue cell-array that can be configured with ‘C’ macros or their translated bit series [28] [18]. The configurable analogue blocks of the FPAA can be reconfigured to operate better (more suitably) and automatically with a self-configuring algorithm. As reconfiguration is performed several times by the device, its actual version will own totally new features in comparison to the ones of its ancestors. This is particularly useful in the design of nonlinear subsystems where there are many inevitable sources which can cause failure of one or more of the components of the control system mounted onboard. Inspite of inherent damping schemes present, shock loads can cause sufficient vibrations of random amplitudes and if vibration inputs occur at resonance frequency or harmonics, vibration displacement will be maximized. As a result of one or more of the above effects, a fault can occur within a control system and fault recovery becomes essential, so as to continue service (atleast degraded service) and maintain system stability. For example, an increase or decrease in the value of a circuit element capacitor decreases or increases the system bandwidth respectively and either filters out useful signal (i.e. system response becomes too sluggish) or allows high frequency noise to enter the system. In worst case these changes can even cause the system to fail. In this context, in this work, a reconfigurable hardware based fault recovery at the system level using FPAA is proposed, implemented and tested. In the event of a fault (for ex: manifested by a
sudden change in the system bandwidth), the proposed reconfigurable hardware introduces self compensating networks so as to meet the stable output requirements. When the design gets implemented the FPAA autonomous reconfiguration model will be of the form as shown in Figure 1.1.

![Proposed FPAA based autonomous reconfiguration model](image)

**Figure 1.1 Proposed FPAA based autonomous reconfiguration model**

1.5 RESULTS DEMONSTRATED IN THIS THESIS

From the obtained implementation results, the following are demonstrated in this research:

(i) An FPAA with variable control law generator has the ability to provide an improved tracking response compared to a conventional PID controller.
(ii) By altering the nature of the control law generator block different forms of optimal control objectives can be achieved. Even though the proposed work could be slightly complex for time variant systems of high order, the discussion and the results obtained provide a starting point for numerical determination of the control law in an optimal sense.

(iii) The performance measure “Integral Square Error” is computed in this research for both FPAA-PID Controller and FPAA with variable control tuned Logic Controller (for servo as well as regulator operations) and is used as a metric to demonstrate the effectiveness of the proposed work. ISE value for servo and regulator response operation is obtained. The values clearly demonstrate that the proposed FPAA with variable control law tuned embedded block has a better response.

(iv) Such an implementation is advantageous when an analytical expression for the switching hypersurface can be obtained and the resultant expression is performed by the control law block in the FPAA. This is particularly useful in higher dimensional systems where switching occur on hypersurfaces in the state space. The FPAA along with the variable control law block acts as a combination of physical devices that perform the optimal control action.

1.6 CONCLUSION

In this research work, it is established that when the same type of control law needs to be implemented across a range of systems, the reconfigurability inherent to the FPAA, allows the designer to easily and precisely implement the changes to tune the circuit for each system. The proposed work can thus adaptively perform either as bang-bang or bang-off-bang or a combination of both the controller by suitably altering the variable control law generator function. The response of the system with the estimator gives an estimate of the variable speed during the time of sensor failure and this estimated value is used (by the Variable
law FPAA Controller) to give the control voltage. The estimated variations in speed with respect to the steady state value for different conditions are studied in this work. The experimental results show that the proposed adaptive controller with the embedded neuro observer (both built using FPAA) is robust and can be used for speed control of motor even when the speed sensor is faulty or inaccurate.

To summarize, in this thesis, (i) An FPAA with variable control law generator provide an improved tracking response compared to a conventional PID controller (ii) By altering the nature of the control law generator block different forms of optimal control objectives are achieved. (iii) Built-in estimator helps in maintaining the system stable even during speed sensor failure.

1.7 OVERVIEW OF THE THESIS

Chapter 1: Introduction, problem statement and proposed solution, objectives of the research work and methodology.

Chapter 2: Literature survey, Benefits of the proposed research work, inference from the literature works are presented.

Chapter 3: Field Programmable Analog Array (FPAA) description, FPAA control platform and integration, FPAA block diagram and description of different programmable functions, Reconfiguration of FPAA.

Chapter 4: Implementation of programmable control law functions into the FPAA. Closed loop control system design with FPAA-FLC (Variable control law module) and implementation of optimal control circuits into FPAA. Response of the system for servo and regulatory operations are presented.
Chapter 5: Design of Fuzzy and Neuro observer for fault tolerant control of motor. FPAA implementation of neuron blocks. Implementation results of Soft (Fuzzy) and data driven (Neuro) estimator based system. Discussion of the sensor noise elimination algorithm is also made.

Chapter 6: Results and discussion. Computation of Performance measure and comparison studies with adaptive (Tuned) PI controller. Comparison of the performance of two estimators and the sensor noise elimination scheme is discussed. The future scope of the work is also presented.