# Accurate Position Estimation in Switched Reluctance Motor With Prompt Starting


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## 1.0 INTRODUCTION

This paper presents a novel method of position estimation for Switched Reluctance (SR) Motor. The method is suitable from starting to full speed. It ensures smooth starting without initial hesitation. The method further incorporates a better position estimating algorithm incorporating corrections for excitation voltage and mutual inductance effects. The algorithm is better suited in a digital control platform for its realisation. Digital signal processor (DSP) with its high computation power has ushered in fresh possibilities for such schemes. In the present work, a general purpose DSP platform is used for the position estimation as well as control of the SR motor. A Texas Instruments make DSP (TMS320c50) is used for this application.

## 2.0 POSITION ESTIMATION

A number of methods have been reported in the literature for the estimation of rotor position in SR motors [1]. Among these methods, those based on the flux-linkage current characteristics have become popular [1, 2]. Figure 1 shows the block schematic of the basis of position estimation. Flux-linkage of any phase is computed from Eq. (1).

$$\Psi = \int (V - R\,i)\,dt \qquad (1)$$

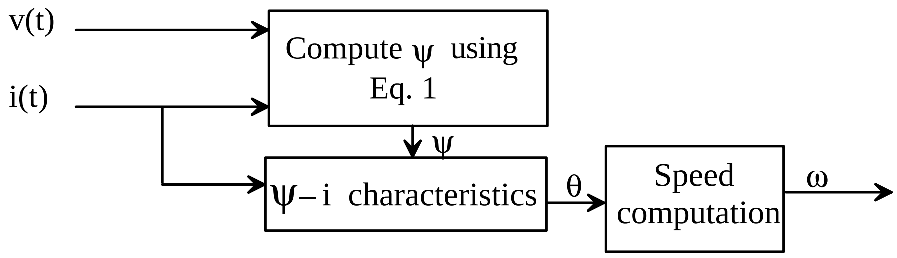


Fig. 1 Schematic of the Position Estimation Method

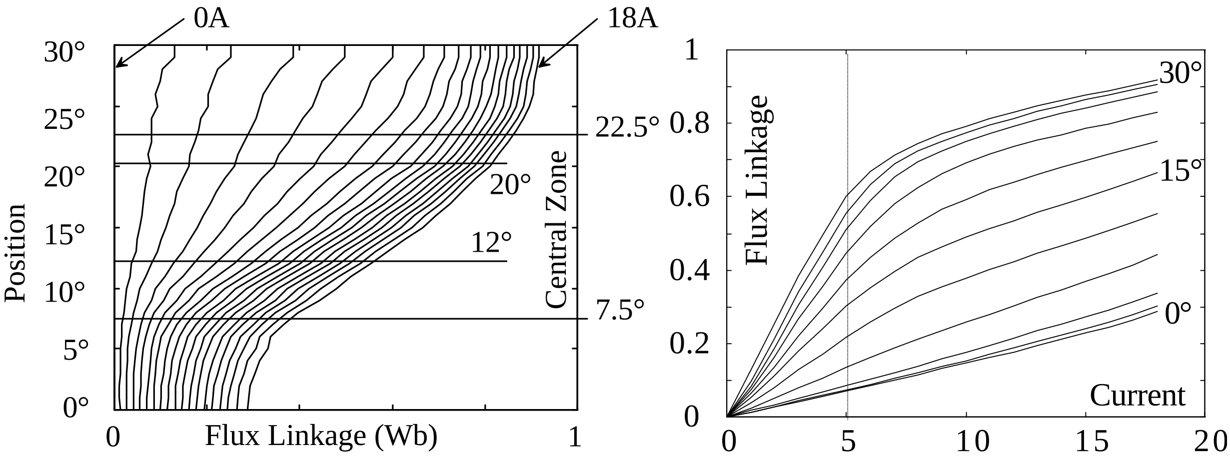

Fig. 2 Flux-Linkage Characteristics

Pre-computed ψ - i characteristics as shown in Fig. 2 is stored in a look-up table to compute position from the measured phase voltages and currents. Position update may be carried out once in a cycle (discrete estimation) with measurement of voltage and current in one phase or on a continuous basis (continuous estimation) with measurement on all four phases.

**3.0 IMPORTANT ISSUES IN POSITION ESTIMATION**

There are several important issues involved in the position estimation method outlined above. These are listed as follows.

1 The ψ - i characteristics are pre-computed. The precomputed characteristics are obtained by tests done under static conditions. These methods do not take into account the non-idealities associated with the dynamic conditions under which the machine is operating. Such non idealities are related to two aspects.

   i The eddy current effects in dynamic condition may influence the $\psi - i$ characteristics of the SR motor. These influences may introdued an error in the estimated position. The eddy current effects are well covered in literature [2].

   ii The static ψ - *i* characteristics does not take into effect the mutual coupling between the various phases during dynamic operation. It is mentioned in literature that these effects can introduce errors in the flux-linkage characteristics as high as ±10% [2].

2. Most position estimation methods do not cover starting condition. It is known that, SR motors with sensorless operation may suffer from starting problem if proper starting algorithm is not adopted.

## 4.0 POSITION ESTIMATION ALGORITHM

The position estimation algorithm reported in this paper is a composite method incorporating the following features.

1. On starting, test excitation is employed to select the appropriate phases to be excited. Direct control of the current injected during starting ensures test pulse in the non-saturated zone of $\psi$ - $i$ characteristics. Following this approach hesitation free prompt starting is possible.
2. On running, the algorithm incorporates the following corrections.
   - i Appropriate phase is chosen for estimation. Whenever, a particular phase is within 7.5° to 22.5° (central zone, c.f. Fig. 2), it is called the active phase and that phase is chosen for position estimation during that period.
   - ii The nature and quantum of corrections required to account for eddy current effects and mutual coupling effects are obtained through off-line measurements. Such corrections are applied to the compke it compatible with the stored static $\psi - i$ characteristics.

## 5.0 POSITION ESTIMATOR REALISATION

The block diagram of the position estimator following the above method is shown in Fig. 3. Six analog signals (the four phase currents and two dc link voltages) are taken as inputs through ADC. All analog signals are processed through software low pass filter (LF) to attenuate the switching and high frequency noises. The estimator logic generation block decides on the active phase. Eddy-current effcet is decided by the rate of change of flux-linkage in the active phase. Thus in this work, the eddy current correction term, $K_{ce}$ , is made a function of $\frac{d\psi_j}{dt}$ . The corrected gradient of flux as shown in the figure is $\frac{d\psi_{je}}{dt}$ . The computed flux obtained through the integration is further corrected for mutual flux due to the other conducting phases. Notice that the integration shown in Fig. 3 is multidimensional.This corrected flux may be treated as same as the static flux-linkage characteristics. From the corrected flux $\psi_{jj}$ and the active phase current $i_j$, position is looked-up from the stored static

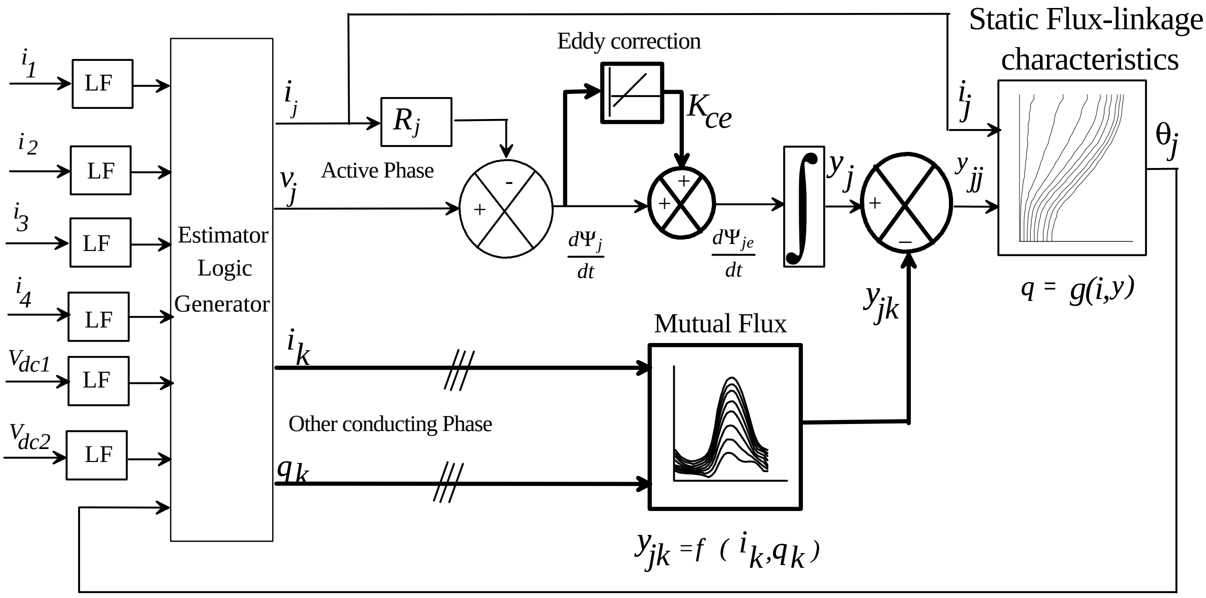


Fig. 3 Block diagram of Continuous Position Estimator using Flux/current Method including eddy-current and mutual flux correction (shown in blod line).

flux-linkage characteristics. From the figure, it may be seen that three look-up tables are searched at every sample time, namely - (i) eddy current correction, (ii) mutual flux and (iii) static flux-linkage. All three look-up tables are obtained through off-line measurements [2, 3]. The flow chart for the complete position estimator including starting algorithm is given in Appendix.

**6.0 CONTROLLER REALISATION**

Apart from the above estimator, the control of SR motor involves a number of operations such as speed computation, execution of speed and current controller, execution of torque to current conversion, T-on and T-off angle selection (Turn-on and Turn-off angle of each phase) and final switching logic generation etc. Besides the estimator, all these jobs are to be carried out once in every sample period. The block diagram of complete controller is shown in Fig. 4. A PI controller serves as speed controller and the current control is through hysteresis.

The execution of the control scheme (including the estimator) as discussed above is time critical. Digital controller is ideal choice for realising such controllers. In this work, a Texas Instruments make, 16-bit fixed point DSP (TMS320c50) is used for controlling the SR motor. A general purpose DSP board is fabricated for realisation of this controller. The

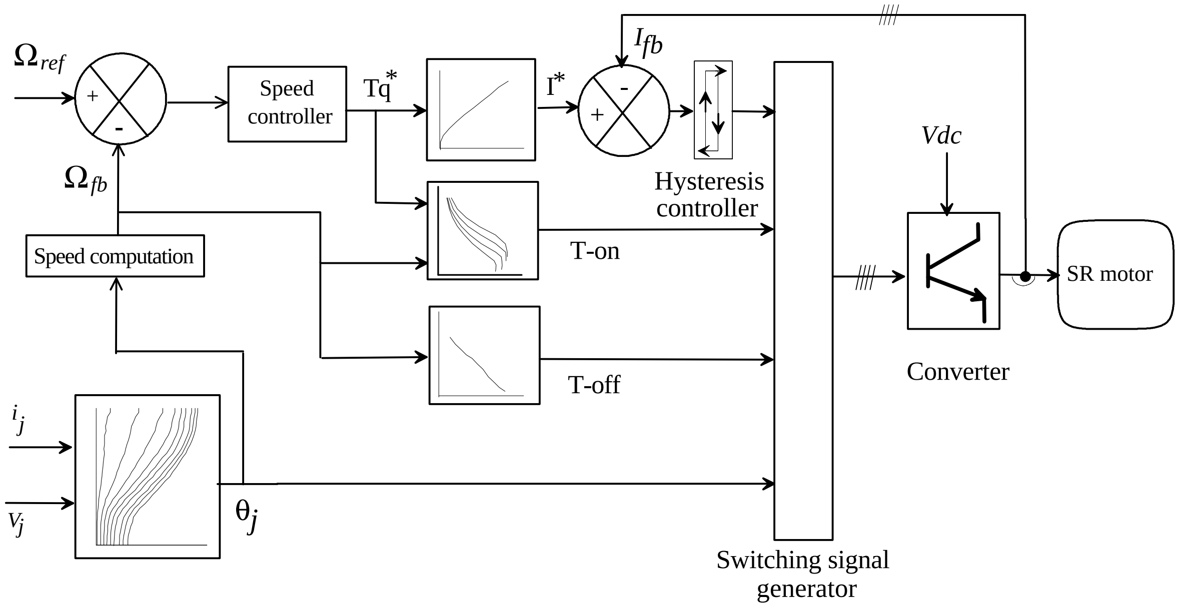


Fig. 4 Controller block diagram with Estimator

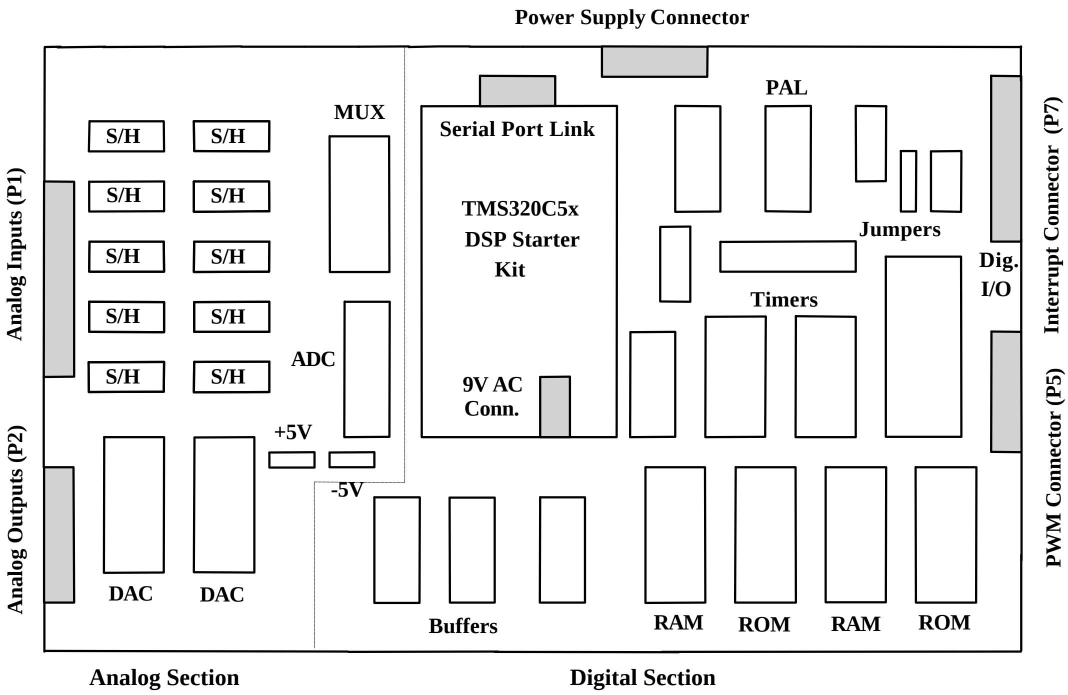


Fig. 5 General Purpose DSP Controller Board

schematic of the board is given in Fig. 5. The board consists of two quad DAC, one 16 channel ADC (1.5 μS conversion time for each channel) with 10 simultaneous S&H circuits, two 8253/8254 timers and one 8255 digital port. Provisions for external RAM and EPROM are kept in case the on chip RAM (9K) is not sufficient. For this particular application, one digital output port and six ADC channels are used. With the help of DSP, the sampling and execution time achieved for the whole process is 100 $\mu s$, which is quite satisfactory for this applications. The algorithm is tested on a 4kW, 4-phase, 8/6 pole OULTON motor. A split-capacitor link power converter is used for controlling the motor. The schematic of the power converter is given in appendix.

**7.0 EXPERIMENTAL RESULTS**

With the above estimation process and TI DSP, it has been possible to obtain position estimation with errors less than ±2° for the 8/6 SR motor at speeds upto 1500 rpm. In order to illustrate the accuracy of the estimation, estimated position is compared with the actual position obtained from a position sensor. A typical test result at 375 rpm is shown in Fig. 6. The motor can start promptly from any position following the proposed method. Figure 7 illustrates the position estimation results and phase current of a particular phase during starting. The speed transient from standstill to rated speed (1500 rpm in this case) with estimated position and with position sensor are given in Fig. 8. The results confirm that the proposed estimator may be used for all practical applications.

**8.0 CONCLUSION**

The discussion and test results in the preceding sections lead to the conclusion that truly sensorless operation of SR motor in the entire speed range including prompt starting is possible. The realisation of the above sensorless controller is feasible with appropriate control platform and estimation strategy. TI DSP with powerful instruction set and high clock rate helps realising such controller.

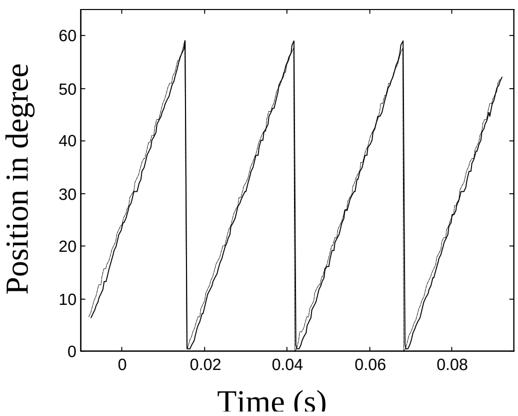


Fig. 6 Comparison of Actual Position (Dotted) and Estimated position (bold) at 375 rpm (steady-state)

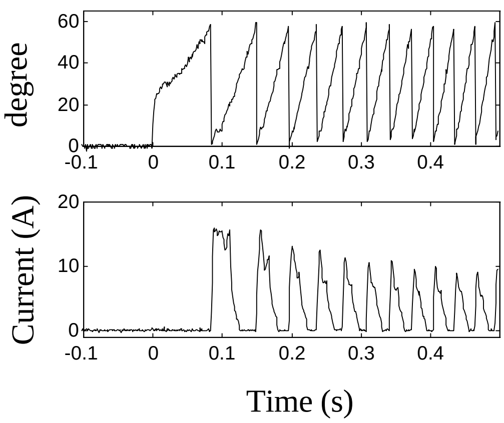


Fig. 7 Estimated Position (Upper Trace) and Phase Current (Lower trace) during starting.

(i)

(ii)

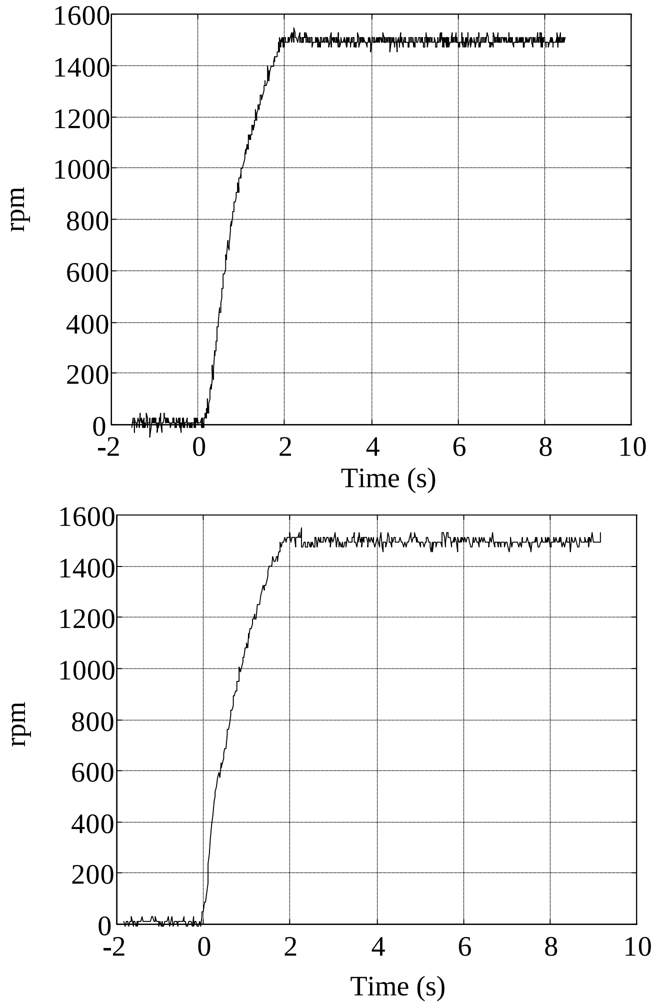


Fig. 8 Test results of Speed Transient: (i) With estimated position, (ii) With actual position from 0 to 1500 rpm

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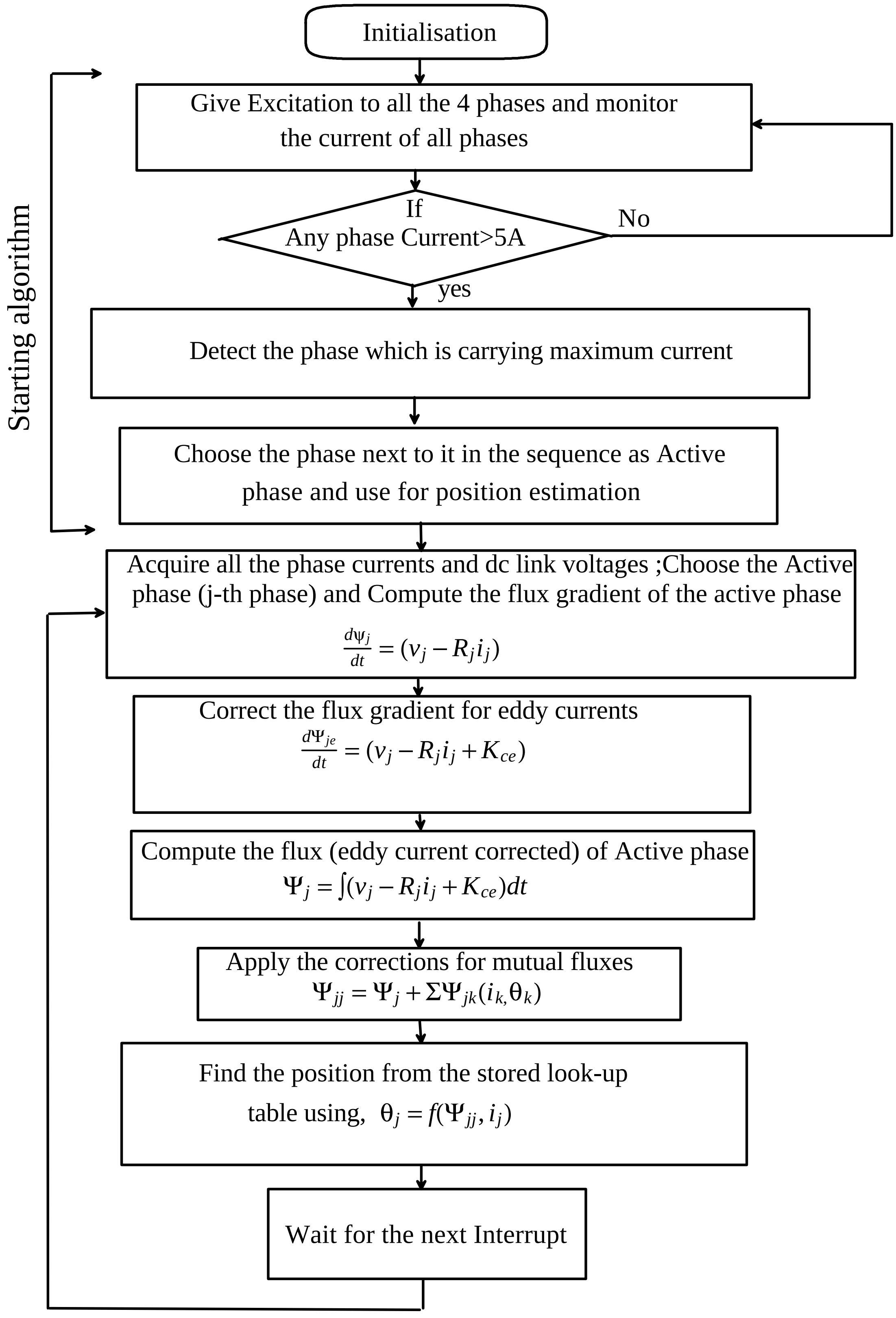
# Appendix

## (i) Flow-chart for the complete estimator including starting algorithm



(ii) Schematic of the Split-link capacitor Converter