Integrated Noise Removal Filter for Switched Reluctance Motor (SRM)

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ABSTRACT
Switched Reluctance Motor (SRM) has simple and solid construction, low-cost, good reliability at high temperatures, and large torque density. Yet, the higher torque ripple from magnetic saliency is a severe problem. This paper experimentally verifies the performance of a switched reluctance motor, the integrated noise removal filter does not require any mathematical modeling of the noise and therefore, can be used effectively to control non- impulsive-type noise. An analysis with the noise and error commonly found in practical motor drives is given, it is shown using experimental results that the NRF scheme can cope well with erroneous and noisy feedback signal and interfacing STM-32 ARM processor.

Keywords
Switched Reluctance Motor (SRM), Noise Removal Filter (NRF), Pulse Width Modulation (PWM), STM-32 ARM Processor.

1. INTRODUCTION
Switched Reluctance Motor (SRM) is a dynamic electrical machine, converting the reluctance torque into mechanical power. SRM is described by singly excited and doubly salient machine, the rotor has no winding or permanent magnets. The structure of the SRM is very simple, reliable, high tolerance and low cost compared to that of natural machines. The application of SRM includes variable speed operations. In SRM the developed torque is non linear function of rotor position and stator current. SRM provide constant power over a wide speed range and is highly dynamic. The torque developed depends on relative position of the phase current with respect to the induction profile. The torque does not depend on the direction of current since the torque is proportional to the square of the current. The developed back emf depends on the magnetic parameters of the machine, rotor position and the geometry of SRM [18].

Nomenclature:

T_m → output torque
j → movement of inertia
B → viscous friction
T_{load} → Load torque
L → unsaturated phase bulk inductance
Ψ → flux linkages
i → current

2. TORQUE EQUATION
The torque developed by one phase coil at any rotor position is given by,

$$T = \left(\frac{\partial w_f^1}{\partial \theta} \right)_{i=constant} \quad \ldots (1)$$

The instantaneous torque is given by,

$$T = \frac{1}{2} i^2 \frac{dL(\theta)}{d\theta} \quad \ldots (2)$$

Saturated torque can be expressed as

$$T = \int_0^i \frac{\partial L(\theta, i)}{\partial \theta} i \, di \quad \ldots (3)$$

The output torque of SRM is given by

$$T_m = \sum_{i=1}^{n} T(i, \theta) \quad \ldots (4)$$

The relation between motor torque and mechanical load is given by

$$T_m - T_{load} = j \frac{dw}{dt} + B\omega \quad \ldots (5)$$

The relation between position and speed is given by

$$\omega = d\theta/dt \quad \ldots (6)$$

It is a set of non-linear partial differential equations, and neglecting the non-linearity due magnetic saturations [2],

$$\Psi(\theta, i) = iL(\theta, i) \quad \ldots (7)$$

$$Ri + L(\theta, i) \frac{di}{dt} + i\, \omega \frac{\partial L(\theta, i)}{\partial \theta} \quad \ldots (8)$$

The average torque can be written as

$$T = \sum_{phase=1}^{n} T_{phase} \quad \ldots (9)$$

In this portion it is assumed that the drive works in the linear region, limited by the saturation value of the current [8]. The drawback of SRM is the high torque ripple [6] and presence of acoustic noise and vibrations [13], [16]. These draw backs are compensated by improving the magnetic circuit at design of motor and by using linearization techniques [5].

3. CLOSED LOOP CONTROL STRATEGIES FOR SRM
The dynamic performance of the switched reluctance motor can be improved by establishing feedback control [1]. The basic functional block diagram of SRM motor drive system is given in Figure 1.

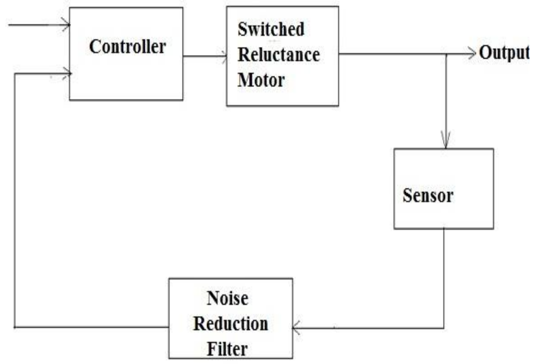

Fig. 1 Block diagram of SRM Controller

Noise reducing filter is used to reduce the noise in SRM [19], and NRF design involves tuning of filters. With the overall NRF, the design of the controller will adapt to the non linear characteristics of the motor. Thus, if the motor characteristics changes with operating conditions, the controller tunings will also change to maintain the desired control performance. The tuning rules are implemented for obtaining the initial settings of the controller and this depends on the application [3].

4. HARDWARE INTERFACE UNIT

JTAG mechanism is traditionally used for the debug connections for ARM7/9 ports, but with the Cortex-M family, ARM introduced the serial wire debug (SWD) Interface and this is followed in this work. SWD reduce the pin count by two required for debug. In addition, one of the pins freed up by this can be used for single wire viewing (SWV), which is a low cost tracing technology. The connection details are shown in Table 1.

Table 1. SWD/SWV Pins Overlaid on Top of JTAG pins /SW Interface

JTAG Mode	SWD Mode	Signal	Remarks	Pin no	Pin details
TCK	SWCLK	Clock into the core	10K-100K Ohm pull down resistor to GND	1	V_{CC}
				2	V_{CC} (optional)
				3	TRST
TDI	--	JTAG Test Data Input	10K-100K Ohm pull-up resistor to V_{CC}	5	TDI
				7	SWDIO/ TMS
TDO	SWV	JTAG Test Data Output / SWV trace data output	10K-100K Ohm pull-up resistor to V_{CC}	9	SWCLK/ TCLK
				11	RTCK
				13	SWO/IDO
TMS	SWDIO	JTAG Test Mode Select / SWD data in/out	10K-100K Ohm pull-up resistor to V_{CC}	15	RESET
				17, 19	N/C
GND	GND	--	--	4, 6, 8, 10, 12, 14, 16, 18, 20	GND

5. IMPLEMENTATION OF NOISE REMOVAL FILTER

Figure 2 shows the various units of STM 32 hardware interconnected to perform noise filtering. Two different variance rates are used to study the performance of NRF. Each case is corrupted with noise of varying standard deviation. The two cases chosen for study have the parameters listed in Table 2. The results are plotted in case (i) and case (ii).

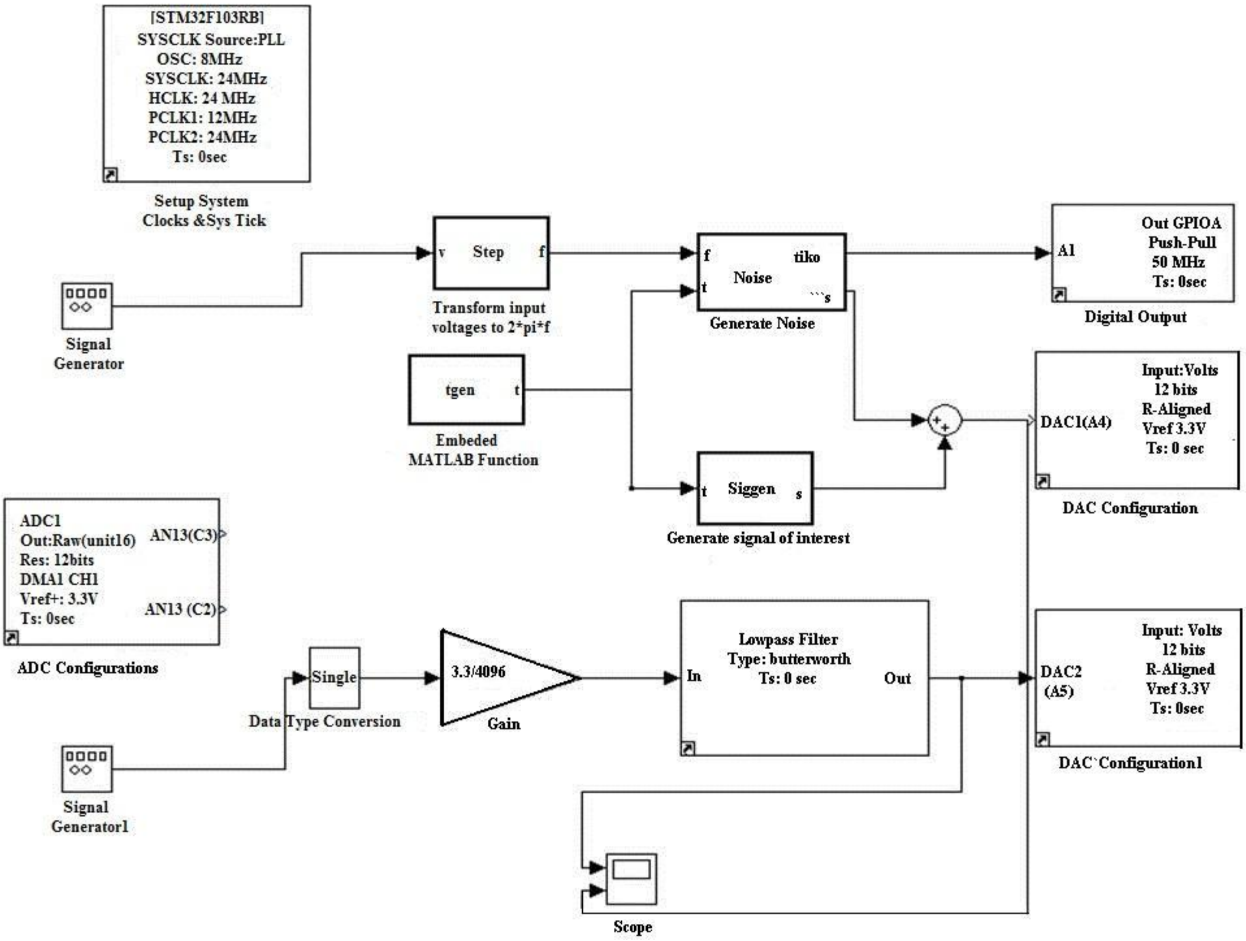

Fig. 2 Noise Removal filter (NRF)

5.1 Case (i)

Table 2. Frequency of Signal NRF

Case	Data rate	Variance (noise)
(i)	5Hz	0.12
(ii)	5Hz	0.2

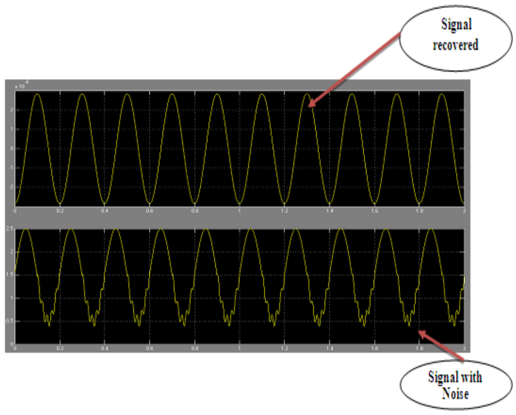

Fig. 3 Performance analysis at low frequency with low Variance Noise

5.2 Case (ii)

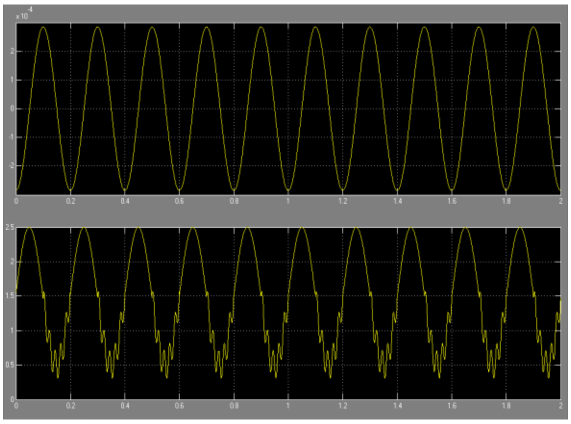

Fig. 4 Performance analysis at low frequency with high variance Noise

6. PWM SIGNAL GENERATOR

The complete reconfigurable architecture used to generate PWM wave form reference sine wave is shown in Figure 5. The generated signals from the block are shown in Figure 6.

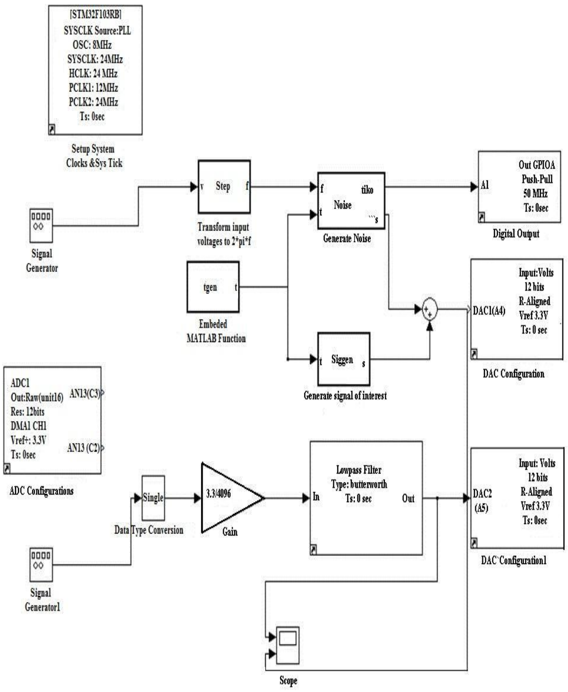

Fig. 5

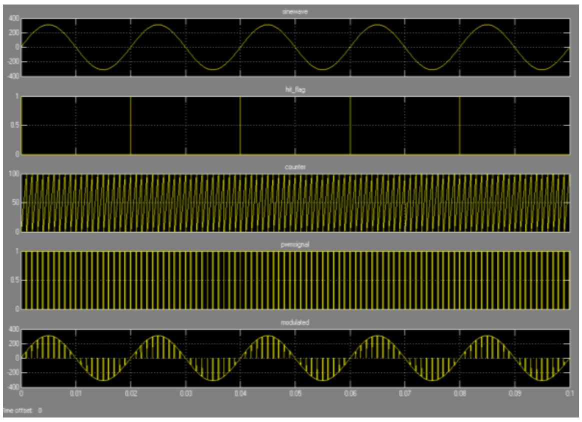

Fig. 6

Time interval detection is performed between low to high multiple PWM signal edges. The methodology involves generating multiple interrupt signals that manipulate count mechanism and track time computation. The accuracy of this scheme depends on the fundamental step resolution (taken as 0.0001 sec. in this work). This block and the output wave form generated is shown in figure 7 and figure 8.

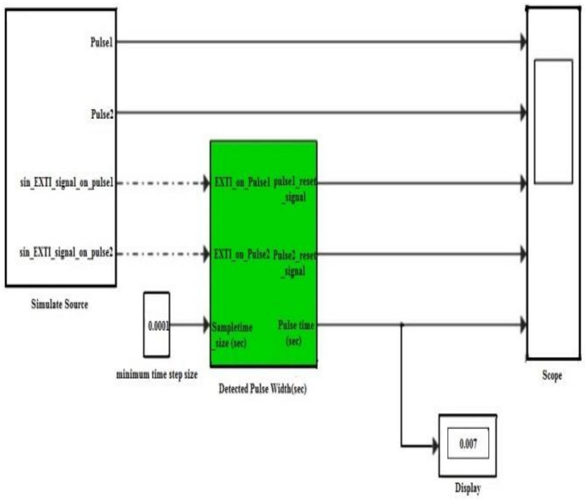

Fig. 7

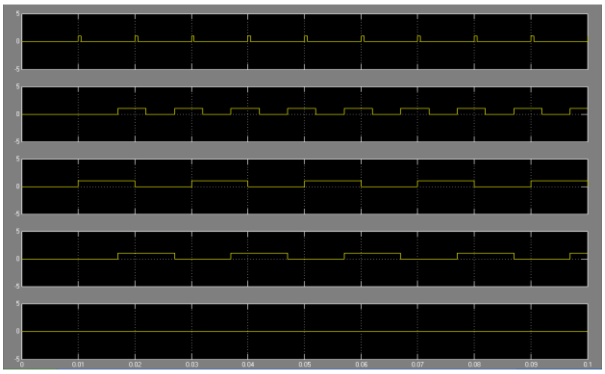

Fig. 8

7. RESULTS AND DISCUSSION

The effects of load variations on current, velocity, output power and the efficiency are simulated. The results are charted in figures 9, 10, 11, 12, 13, 14. Figures 10 and 11 shows the current and velocity shapes for various load conditions (the velocity decreases with an increase in load).

Figures 12, 13, 14 exhibit the characteristics of mechanical power and efficiency. It can be seen that initially, as the load increase, the efficiency increases and when the load is further increased the efficiency starts to decrease.

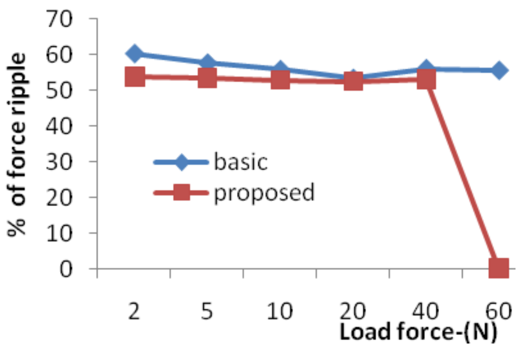

Fig. 9 Comparison of basic and proposed scheme (% forced ripples with load)

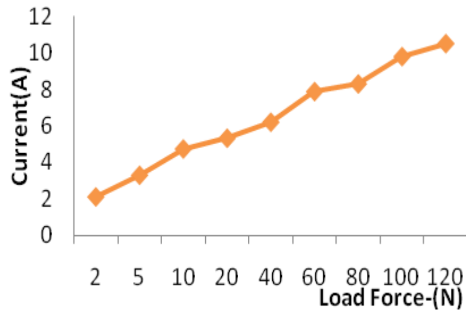

Fig. 10 Current vs load Variations

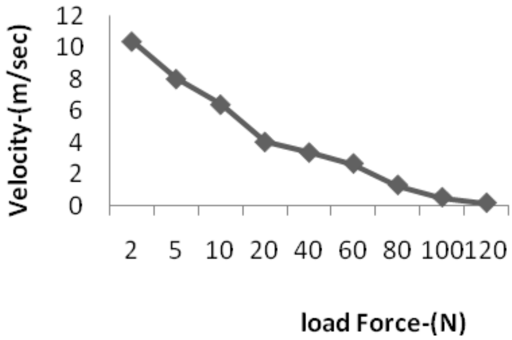

Fig. 11 Velocity vs load Variations

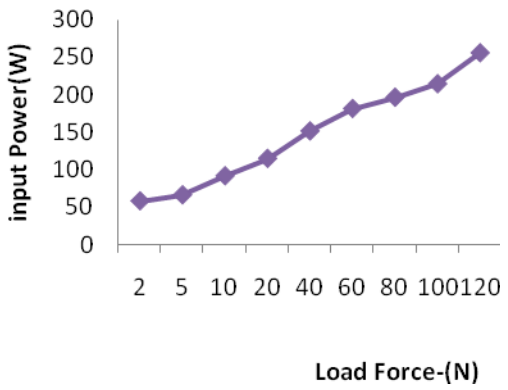

Fig. 12 Input power vs load Variations

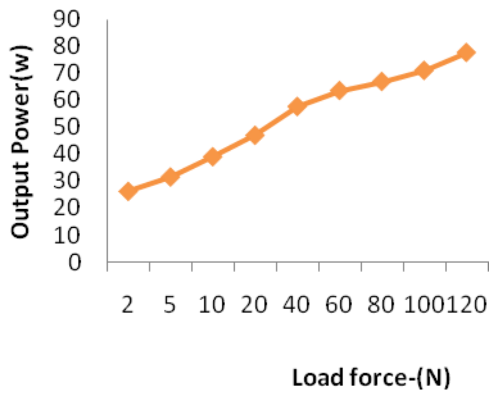

Fig. 13 Output power vs load Variations

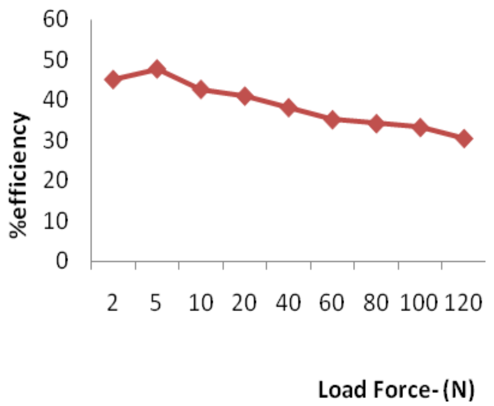

Fig. 14 Efficiency vs load Variations

8. CONCLUSION

SRM has its uniqueness since it is a kind of motor without permanent magnet. Its characteristics have the feature of non linearity. The switching harmonics of phase voltage and current in a PWM period are used for the purpose of estimating the incremental inductance from which the flux linkage can be estimated. The estimated flux linkage is useful in identifying the position and speed of the rotor in a PWM period. In this paper, the configurable hardware system was developed, simulated, and investigated. The noise removal filter was also presented to reduce noise in SRM. The results represent the effectiveness of the designed Noise Removal Filter. The proposed configuration reduces the torque ripple by 6%. Future research, in the field, may consider further reduction of noise in SRM.

9. ACKNOWLEDGEMENT

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10. REFERENCES

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