



Study of SRM in MATLAB Simulink Environment

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Abstract: Switched reluctance motor (SRM) is increasing a lot of interest in mechanical applications, for example, wind based energy systems and also the electric vehicles because of its straightforward and rough development, high - speed activity capacity, heartlessness toward high temperature, and its highlights of adaptation to internal failure. Switched Reluctance Motor (SRM) is otherwise called Variable Reluctance Motor. This motor deals with the standard of variable reluctance. This implies, the rotor consistently attempts to adjust along the most reduced reluctance way. As the name proposes, an exchanging inverter is needed for the activity of Switched Reluctance Motor. Right now, the switched reluctance motor (SRM) is viewed as perhaps the most ideal alternative for working EVs due for its potential benefits of basic structure, ease, high unwavering quality, high force age, and high proficiency at a wide scope of speeds. The immediate and aberrant estimation techniques for SRM attractive attributes are incorporated; examination between the deliberate and determined qualities is accomplished.

I. INTRODUCTION

SRMs have an overload stator with two shafts and also the rotor posts with N_r equals to $2 \times m \times q$, where $m =$ is means the stage quantity. Each stage has a loop on the stator posts. The most well-known SRM structures 6:4 and 8:6 are one among (now with the principal figure manifesting the number of stators based shafts and then secondly number indicating the quantity of rotor posts), as showed in Figure 1 (a) and (b). If the q 's are equal to each other ($q = 1$), then a single loop is placed on every stator. It's possible to have 2 loops as well, or the 3 loops in 8:12 or 12:18 setups. To reduce torque zones, we pick β_s in-sync with β_r where possible. [1]

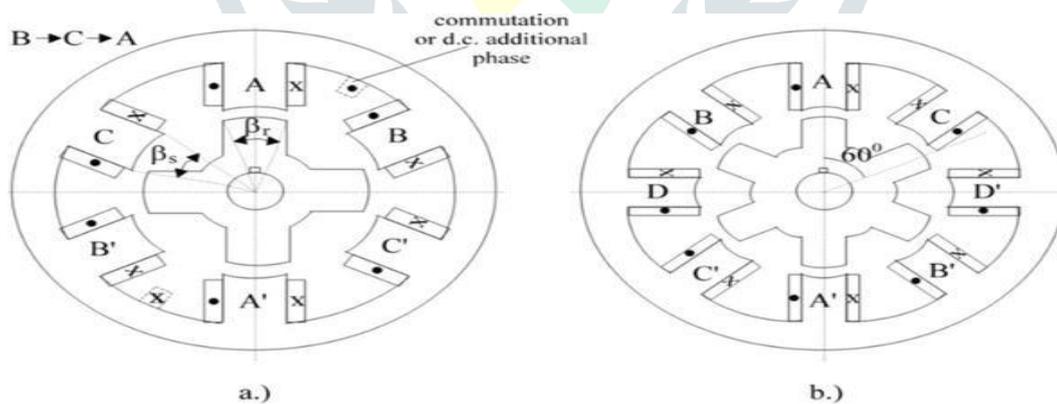


Fig 1: 6:4 of the three - phase and 8:6 of the four - phase based configurations.

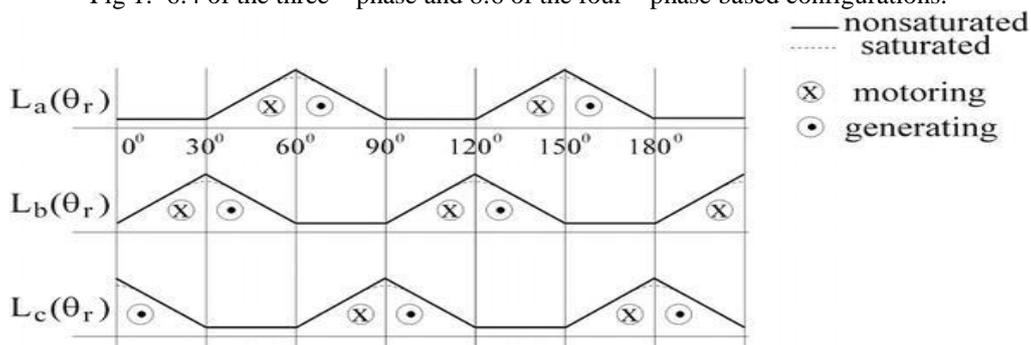


Fig 2: 4:6 SRM Phase inductance and the operation modes

The shapes of $\lambda(\theta_r, I)$ curves are influenced by the position of the rotor, as shown in Figure 3. Immersion can be seen in this figure in a motor that has not been appropriately designed.

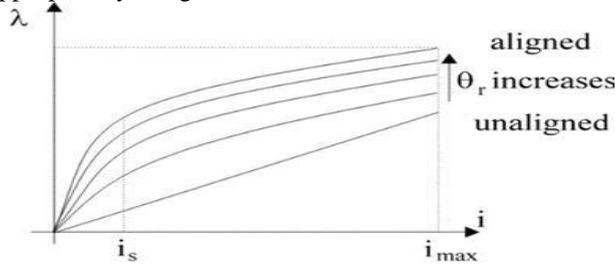


Fig 3: $\lambda(\theta_r, i)$ curves.

“On the off chance that the $W_{mc}(\theta_r)$ co - energy is known, the second torque of $T_e(I)$ stage can be determined through Eq. (1):

$$T_e(i) = \frac{\partial W_{mc}(\theta_r)}{\partial \theta_r} \Big|_{i=\text{const.}}; W_{mc} = \int i_0 \lambda(\theta_r, i) di \quad T_e(i) = \frac{\partial W_{mc}(\theta_r)}{\partial \theta_r} \Big|_{i=\text{const.}}; W_{mc} = \int i_0 \lambda(\theta_r, i) di \quad E1$$

To figure Eq. (1), the class of $\lambda(\theta_r, I)$ bends should be determined through Eq. (2) as follows:

$$T_e = \sum_{i=1}^m T_e(i) \quad T_e = \sum_{i=1}^m T_e(i) \quad E2$$

The second torque can be estimated through Eq. (3) in situations when there is no immersion:

$$T_e = \sum_{i=1}^m \frac{1}{2} i^2 \frac{\partial \lambda_i(\theta_r)}{\partial \theta_r} \quad T_e = \sum_{i=1}^m \frac{1}{2} i^2 \frac{\partial \lambda_i(\theta_r)}{\partial \theta_r} \quad E3$$

In a perfect world, when the rotor shafts are set between the two posts of the stator, the stage is energized a similar way to make motoring capacity. This is appeared in Figure 4 where the voltage beat is just applied for the conduction point $\theta_{\omega} = \theta_c + \theta'$.

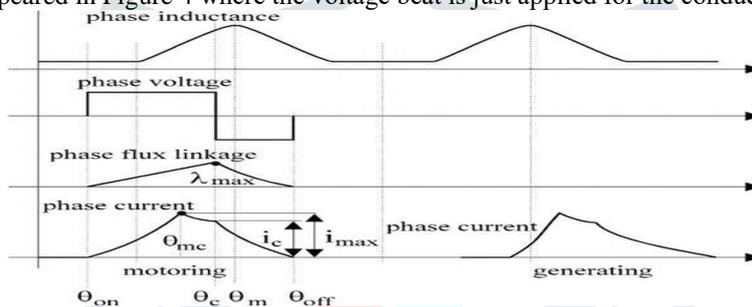


Fig 4: Phase based inductance, the phase based voltages, the phase flux based linkages and the phase based currents

The speed at a baseline is comparable to ω_{\max} based on optimal conditons, single heartbeat voltage applied with plentifulness, and the greatest stage transition link. Accordingly, it may be recommended that the base speed is subject to the motor plan and the immersion level. As the speed outperforms the base speed, the motor's attractive circuit is immersed.

For the speeds higher than that of the base speed ($\omega_r > \omega_b$) ω_{ω} should diminish marginally, and accordingly, the greatest stage motion linkage (λ_{\max}) should be decreased to a specific sum, a wonder known as transition lessening. Furthermore, in speeds over the ostensible speed, to accomplish the most extreme stage motion linkage (λ_{\max}) at a more modest θ_c point and the greatest stage motion linkage (λ_{\max}) at a more modest θ_c point, and eventually to produce more torque, the stage terminating point (θ_{on}) should be driving contrasted with ordinary conditions. Subsequently, the envelope of the torque - speed bend increments as needs be. Then again, the stage deactivating measure begins at $\theta_c \leq \theta_m$ and closes in the creating zone at θ_{off} . A diminishing in $\theta_{off} - \theta_m$ point will decrease the portion of negative torque in the deactivating cycle. By and by, if at $\theta_r = \theta_m$ the current worth is under 25–30%, the impact of negative torque will be unimportant [5].

At the point when a stage is cut at a point θ_c , the other stage turns on and in this manner the complete pace of the torque brought about by the interference of the current in the past stage is diminished through creating a positive torque.

We have observed that the attractive energy of each stage at the controlled time increments and then decreases. This phenomenon is repeated in each of the mechanical rounds for $m \times N_r$ times. At each stage, a portion of the attractive energy is wasted by electronic force converters, and the rest is left for DC interfaces to return and for capacitors inside converter-based channels. Underneath the base speed ω_b current is inhibited with help from PWM converters as seen in Figure 5..

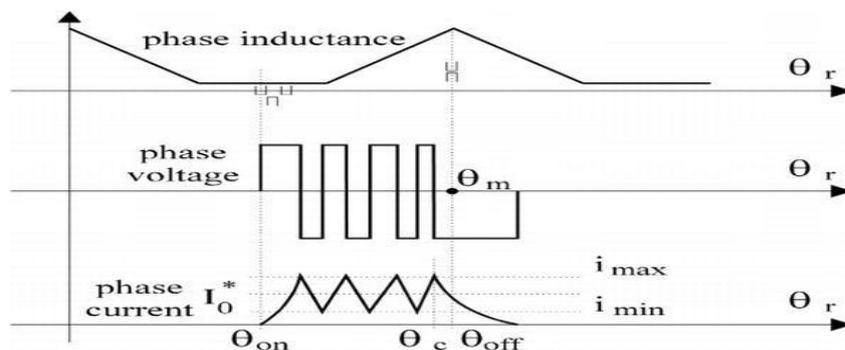


Fig 5: PWM converter Current and the voltage controls

It should be also reminded that the conduction based time keeps going close to the point θ_m , at which the inductance stage point is most extreme. As it was referenced before, the terminating stage point at high speeds is θ_{on} and the mood killer point is θ_c driving.

II. PROPOSED WORK

Switched Reluctance Motor

The Switched Reluctance Motor (Srm) is an electric based motor one that runs by the reluctance based torques. Not in any way like fundamental brushed DC based motor sorts, power is passed on to the windings in the stators (cases) instead of the rotors. This tremendously smoothes out mechanical arrangement as power shouldn't be passed on to the moving parts, yet it catches the electrical arrangement as a sort of trading structure should be used to pass on ability to the different type of windings. The Electronic devices can also precisely performing time trading, and empowering SRM plans. Its essential detriment is torque ripple.[1] Controller development that also limits the torque swell at low speeds has been demonstrated.[2] Sources contrast on whether it is a sort of the stepper-based motor or not.[3]

Simple Switching

If the posts the A0 and the A1 are stimulated, by then the rotors will change itself to these shafts. At whatever point this happened it is useful for the stator presents on be de-invigorated before the stator shafts of the B0 and the B1 are then engaged. The rotor is by and by arranged at the stator's shafts b. Also, this progression continues through c before appearing back around the start. This progression can similarly be turned around to achieve development the other way. High loads and also high de/stimulating can destabilize this progression, making a phase be missed, with the ultimate objective that the rotors then jumps to the wrong point, possibly returning one phase instead of forward three.

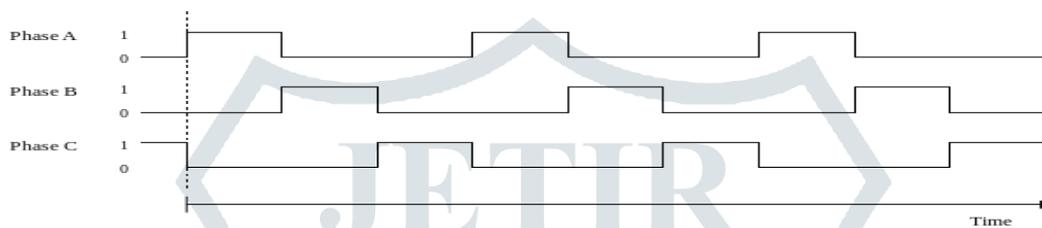


Fig 6: Simple Switching

Quadrature

A fundamentally steadier structure can be then found by using a "quadrature" progression. As at whatever point two twists are invigorated, first, the stator posts the A0 and the A1 are engaged. By then stator shafts of the B0 and the B1 are then animated which in return then pulls the rotors so it is changed in An and B. Following that, this present A's stators posts are de-enabled and also the rotors then continue to be agreed with the B. The progression continues also through the BC, the C and also the CA in order to complete the full turn. This progression can be switched in order to achieve development the other way. More walks between the positions with vague magnetisations, so the start of missed advances occurs at the higher speeds or the loads.

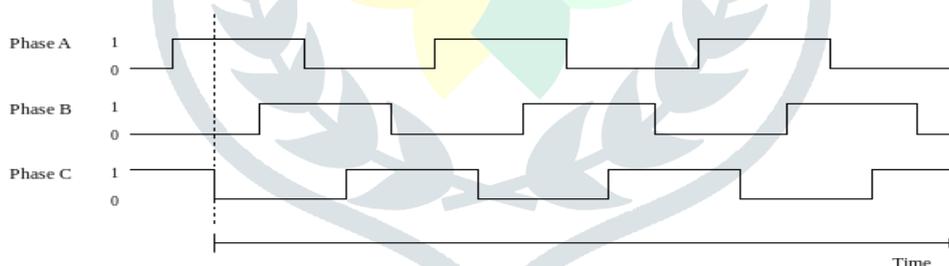


Fig 7: Quadrature

Despite all the more consistent movement, this approach prompts a commitment example of every time of 1/2, rather than 1/3 as in the simpler gathering.

Control

The control system is then also responsible for the giving the important of the progressive based pulses to the power equipment's. It is then also possible to do this by then using the electro-mechanical strategies, for instance, commentator's or essential straightforward or timely arrangement circuits.

Various controllers meld programmable reasoning controllers (PLCs) rather than electromechanical parts. The microcontroller one that can be used to engage definite arranging of stage incitation. It in like manner enables a sensitive starting limit in programming structure, to decrease the proportion of gear required. An analysis circle overhauls the control system.[1]

Asymmetric extension converter

The most notable approach to manage controlling the switched reluctance-based motors is to use an unbalanced expansion converter. The trading repeat can be on different occasions lower than for AC motors.[3]

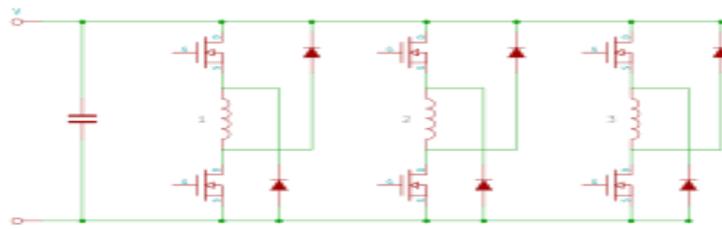


Fig 8: Circuit Diagram

The stages in a hysteresis current controller contrast with the times of the switched reluctance-based motors. If then both of the powers then turns on one or the other side of the stage are turned on, by then that looking at stage will be affected. At the point when the current also has risen above the set worths, the switch slaughters. The energy as of now set aside inside the motor wrapping keeps up the current a comparative route until that energy's are then depleted.

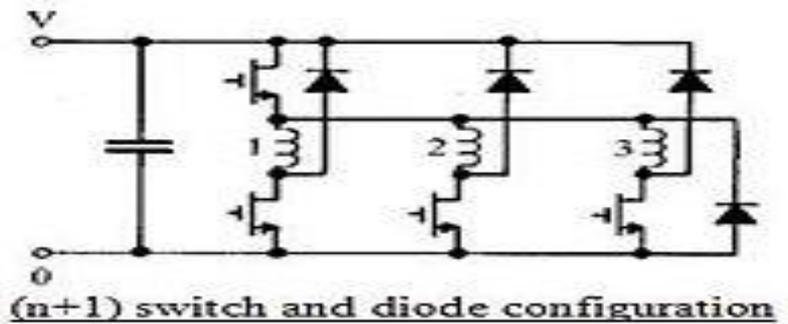


Fig 9: N+1 switches and diodes

This basic equipment may be adjusted with the objective that less sections are needed notwithstanding the way that the circuit plays out a comparative movement. This successful circuit is then also known as the (n+1) switches and the diode game plan.

A capacitor, in one or the other arrangement, is used to cover electrical and acoustic upheaval by confining instabilities in the effortlessly voltage.

Modelling Techniques

- **Look-Up table Approach**

The Switched Reluctance Based Motor (SRM) then block speaks to three most basic switched reluctance-based motors: the three-stage 6/4 SRM, the four-stage the 8/6 SRM, the five-stage 10/8 SRM, as appeared in the accompanying figure.

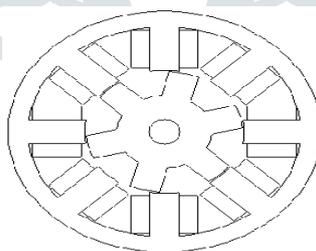


Fig 10: SRM Block

The electric piece of the motor is spoken to by a nonlinear model dependent on the charge trademark made out of a few polarizing bends and on the torque, trademark registered from the polarization bends. The repairman part is spoken to by a state-space model dependent on dormancy second and gooey rubbing coefficient.

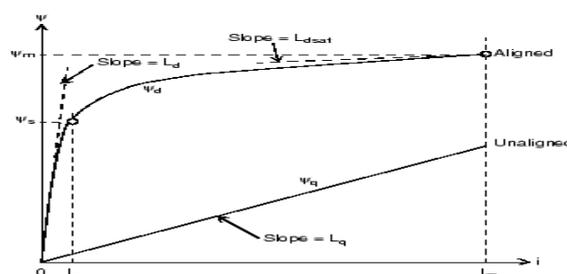


Fig 11: Finite-Element Analysis

- **Analytical Modeling**

The model engages choosing immensely critical motor sums, for instance the store stage current, electromagnetic torque, change thickness in the stator shaft, and extended force following up on stator post of the SRM, as time limits subject to motor limits and action conditions, with precision required for tendency improvement plans. A steady speed and one heartbeat mode action of the motor is normal in the figuring. Some basic results had been appropriated in [5], other point by point information can be found in [6]. The course of action of data sums in the blend program includes such motor limits as: numerical estimations $r_o, r_{sy}, r_{sp}, r_{ry}, r_{sh}, b_{sp}, b_{rp}, g$ (Fig. 12), focus length l , the amount of turns per stage winding N_{tph} , separation across of a conductor, the DC voltage E giving stage circuit, the rotor daring speed and expected data dynamic power P_{in} . At the beginning of figurings subject to the reluctance network method, the stage winding inductance $L(i, \varphi)$ is settled as a component of stage current I and exact rotor position φ .

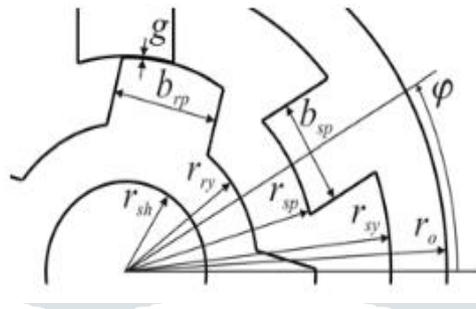


Fig 12: General Parameters of Construction of SRM

In this philosophy the cross-portion an area of the middle is parceled on different districts with consistent alluring movement called "change tubes", Some numerical assessments had been performed to check an effect of chambers number and their arrangement on calculation exactness (basing upon FEM figurings related to the basic turn of events) and time. It had been found that 6 cylinders offer the best compromise for the analyzed turn of events. Understanding non-straight arithmetical conditions portraying simple alluring circuits for all chambers makes it possible to determine major sums, explicitly the stage winding inductance φ .

- **ANN Based Modelling**

Among the computerized reasoning procedures, fluffy rationale and fake neural organizations (ANNs) are used to show the nonlinear alluring qualities of SRMs. They have been represented in SRM illustrating, a two-layer monotonous ANN is used to recognize the damper streams and resistance of stage curving from working data. By this showing technique, the specific nonlinear model can be gained. In like way, complex explanations and fitting counts are skirted. A four-layer back-spread (BP) ANN is applied to evaluate the electromagnetic characteristics under the stator winding blemish condition. In like manner, fluffy rationale systems furthermore have strong nonlinear assessment limit. A fluffy rationale system is grasped to depict the electromagnetic qualities, which shows high steadfastness and strength. On this reason, an improved fluffy rationale system is executed and it just requires 264 rules diverged from right around 1000 principles while keeping up a high precision. It should be seen that the knowledge strategies require a high number of assessed tests to set up the coordinate or make the guidelines.

III. SIMULATION & RESULT ANALYSIS

- **Tools and Technology Used**

MATLAB may be a programing language made by MathWorks. It began as a framework programing language any spot direct factor on a very basic level based science composing PC programs was fundamental. It alright is in like manner run each underneath smart meetings and as a bunch work. This educational exercise offers you commandingly a fragile presentation of MATLAB programing language. it's expected to allow understudies acknowledgment with MATLAB programing language. Issue fundamentally based MATLAB perspectives are given in basic and basic manner to manage make your jumping on quickly and persuading.

MATLAB (framework assessment office) may be a fourth-age atypical state programing language and insightful condition for mathematical tally, portrayal and programming. MATLAB is made by MathWorks.

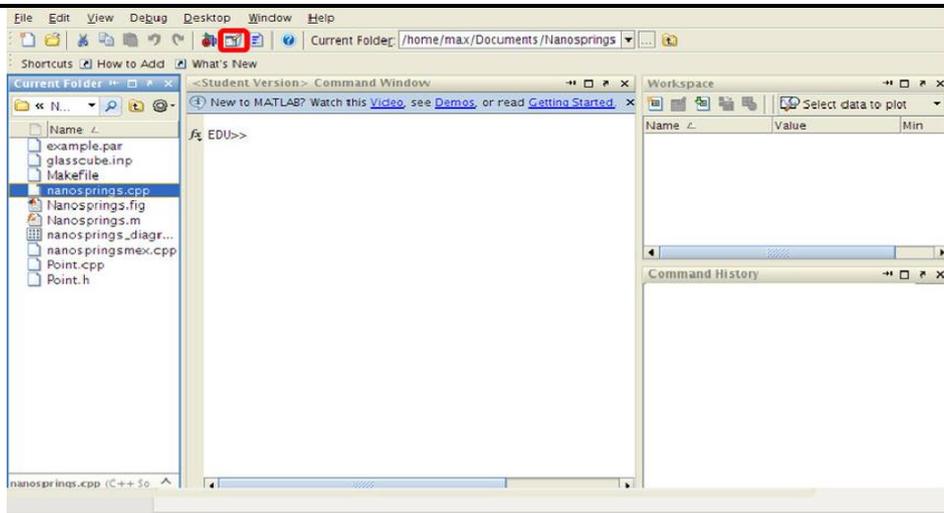


Fig 13: Matlab Interface

It then grants system based controls; the plotting of the limits and also the information; utilization of the counts; generation of the UIs; also then interfacing with comes written in various dialects, together with C, C++, Java, and

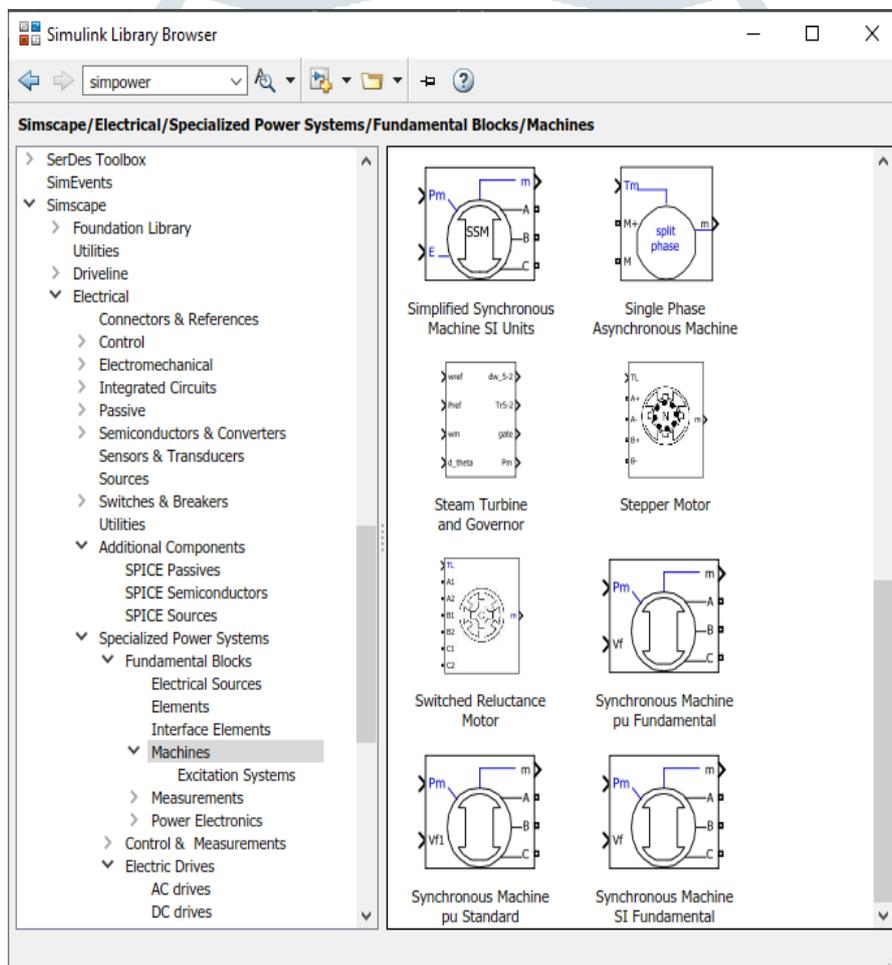


Fig 14: Simulink Library Browser

In the fig 14 shows the Simulink Based library browser , to add the Switched Reluctance Motor , first we have to open the library browser , and then select the SimScape and in the Simscape section , in the Specialized Power Systems , we have to select Machines and from the machine select the Switched Reluctance Motor and drag on the screen.

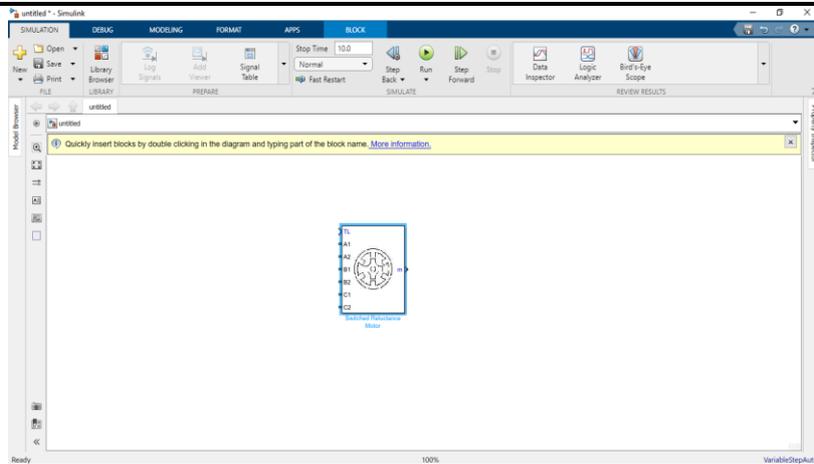


Fig 15: Switched Reluctance Motor Simulink

The default 6X4 model is plotted, that is the 6 rotor poles and 4 stator poles and it is the three phase model, in which the a1, a2 are 1-phase, b1,b2 are 2-phase and c1,c2 are 3-phase. In this TL is the load torque, here load torque is the input from the component from the Simulink library to complete the circuit. M is for the measurement where we can measure the Current, Flux etc.

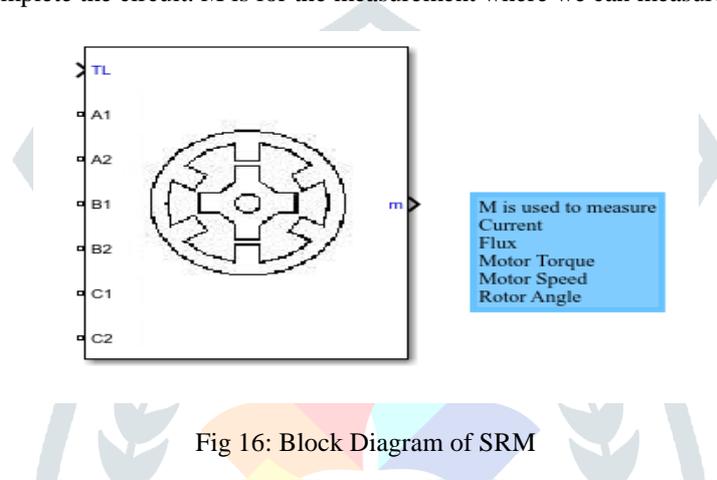


Fig 16: Block Diagram of SRM

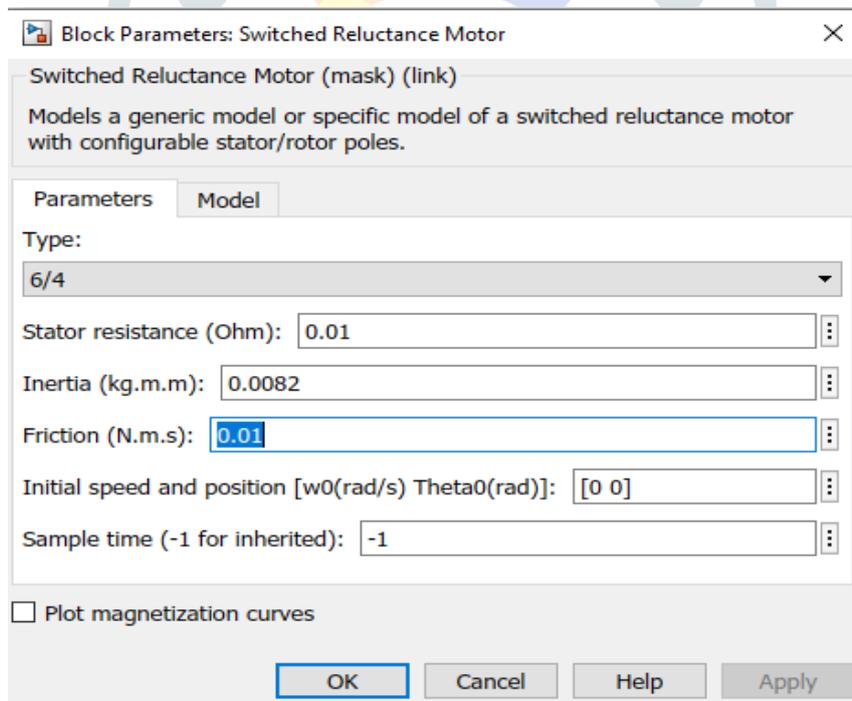


Fig 17: Parameters of SRM

The fig 17 shows, the general parameters of SRM which contains the Type which is default 6/4, Stator Resistance Inertia Friction, Initial Speed and position and also the Sample Time. Initially, the motors are at the zero-reference position in which the initial speed is 0 and position is also 0.

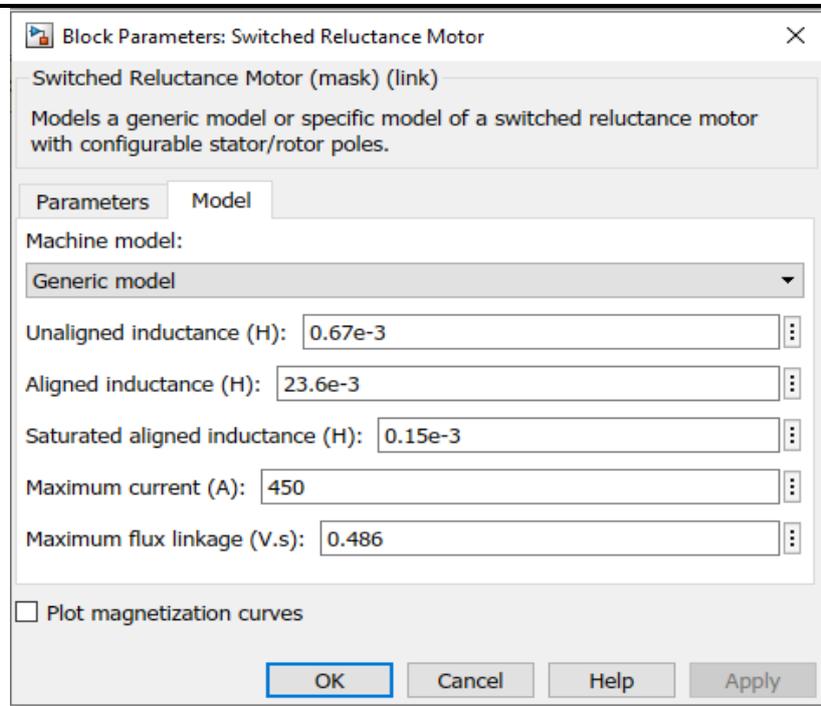


Fig 18: Model Specification

The fig 18 shows the model specification related setting, in which the default model which is selected is the generic model in which we can configure the stator and rotor poles by the specification of the Unaligned inductance, saturated aligned inductance and more.

The unaligned inductance remains the same, while the aligned inductance reduces with the increase of the current.

Now, we will plot the magnetization curves to get the idea of the flux characteristics, the magnetization curves are shows in the Fig 19.

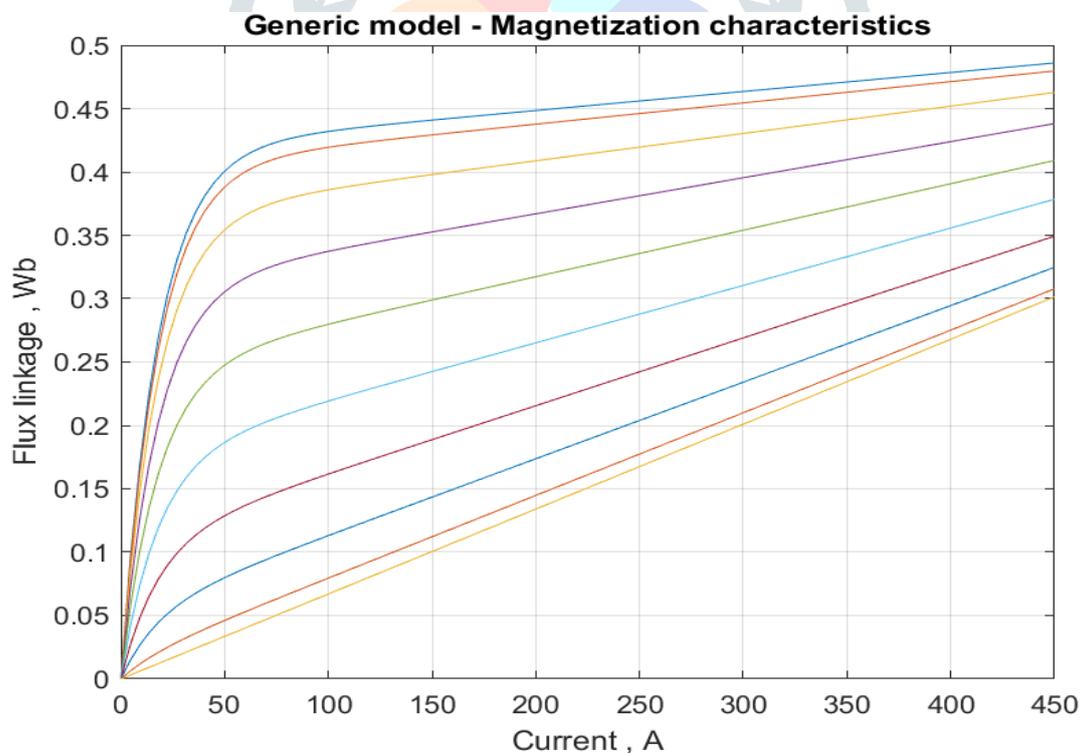


Fig 19: Magnetization Curves in generic Model

In the generic model, as the motor is running most of the time below the saturation point.

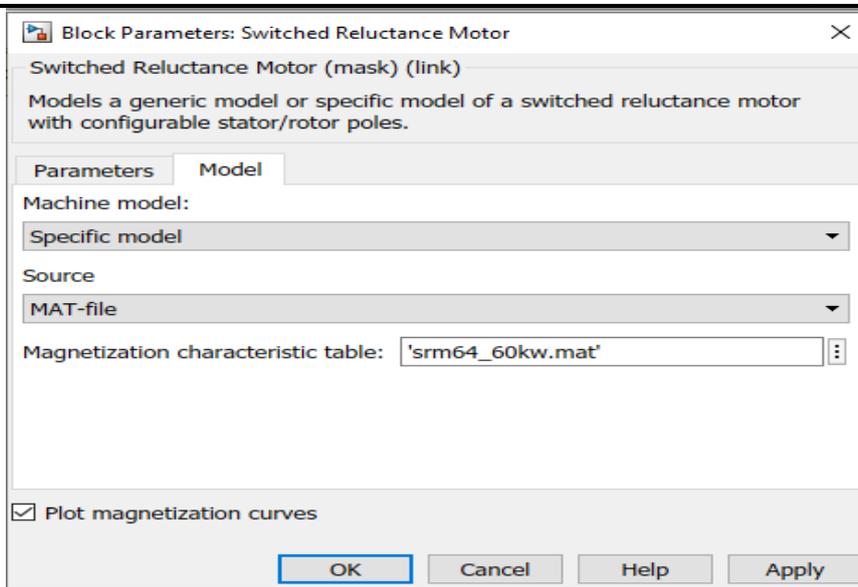


Fig 20: Specific Model 6/4 Reluctance Motor with 60 KW

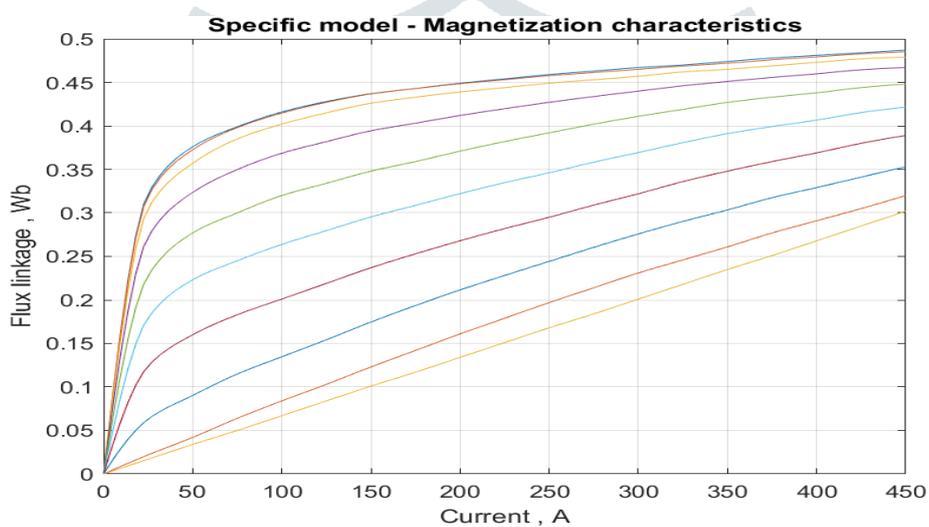


Fig 21: Specific Model Magnetizing Characteristics

For the simulation purpose, we have taken the generic model and the first component which we place is the Bus selection as shown in the Fig 22.

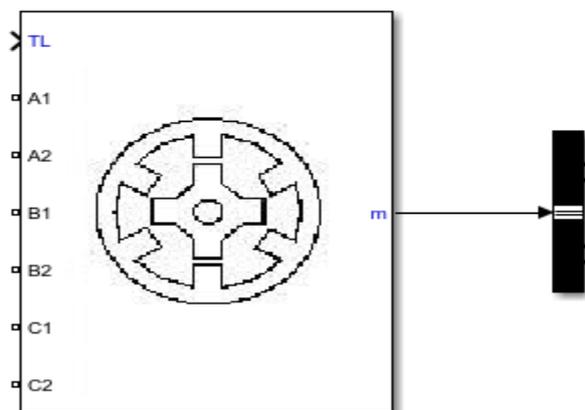


Fig 22: Bus Selector

Now , after attaching the Switched Reluctance Motor with the bus selector , we have to specify the parameters for the bus selector , for this purpose , we have to double-click on it and the bus parameters dialog box will appear on the screen as shows in the Fig 23.

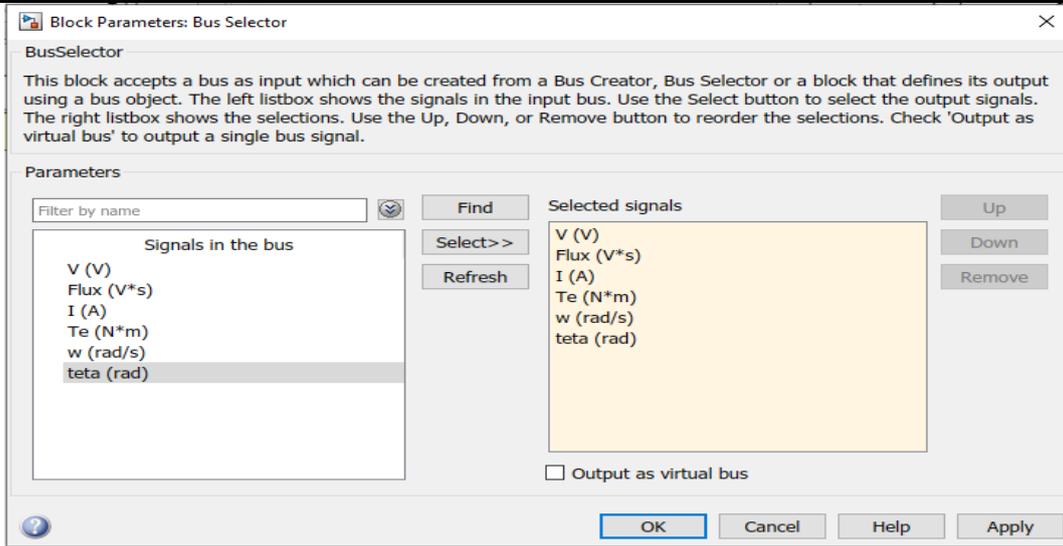


Fig 23: Bus Parameters

In the bus parameters, we have to specify current, flux etc for the selected signals as show in the selected signals section.

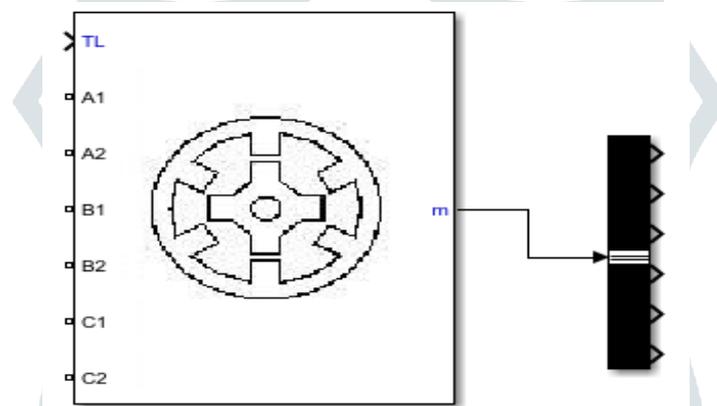


Fig 24: Signals Specification in Bus Selector

The fig. 24 shows the signals which we have selected in the earlier step.

Now , we will add on the scope from the Sink section of the Simulink Library browser, as shown in fig 25.

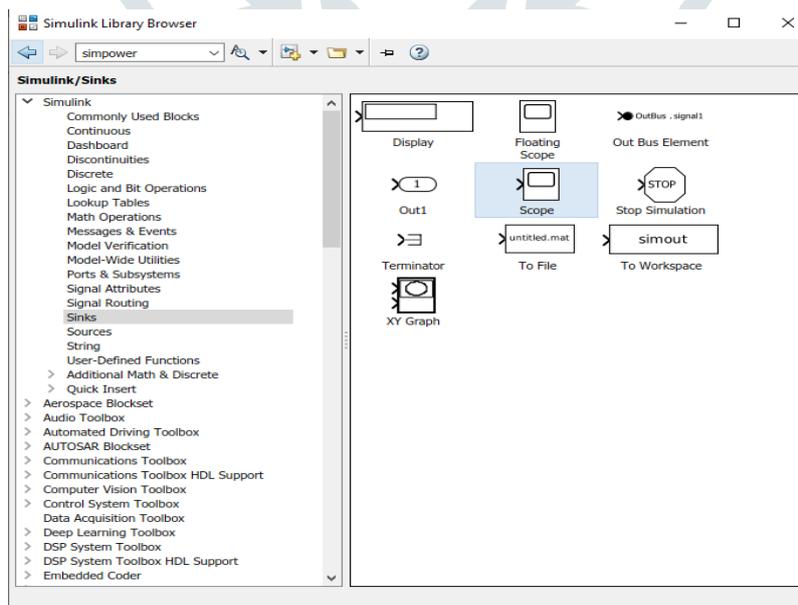


Fig 25: Scope Addition

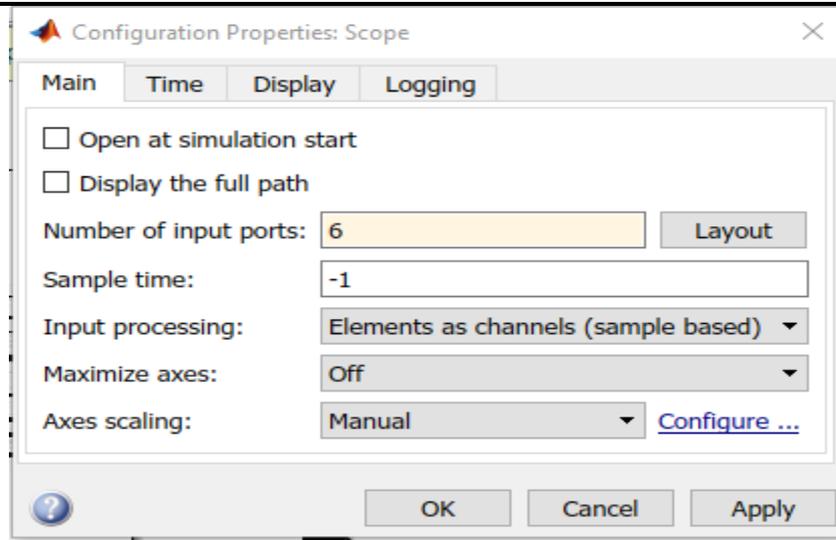


Fig 26: Port Specification in Scope

In the fig 26, we have specified the 6 ports for the scope to link it with the 6 outputs of the Bus Controller.

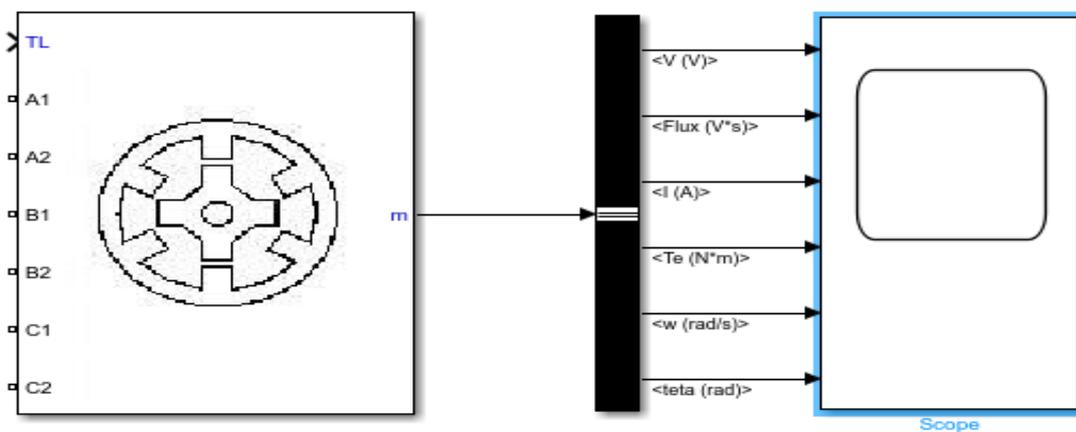


Fig 27: Scope connected to Bus Controller

Now, we want the speed in revolution per second, so we will add on the gain in it, to get the speed in the revolution per second.

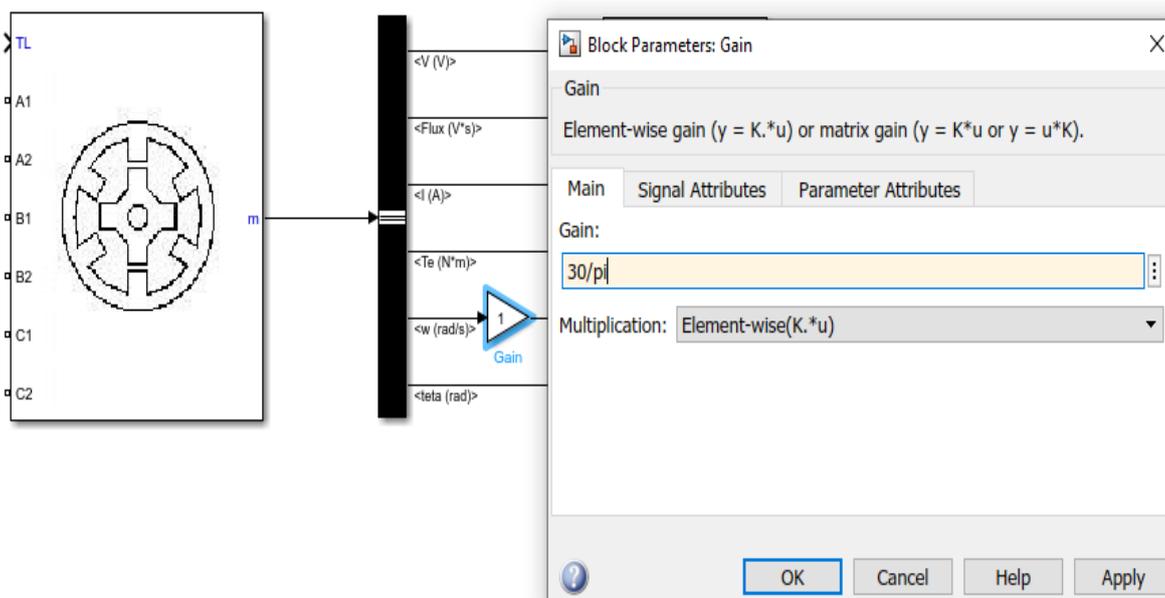


Fig 28: Gain Addition

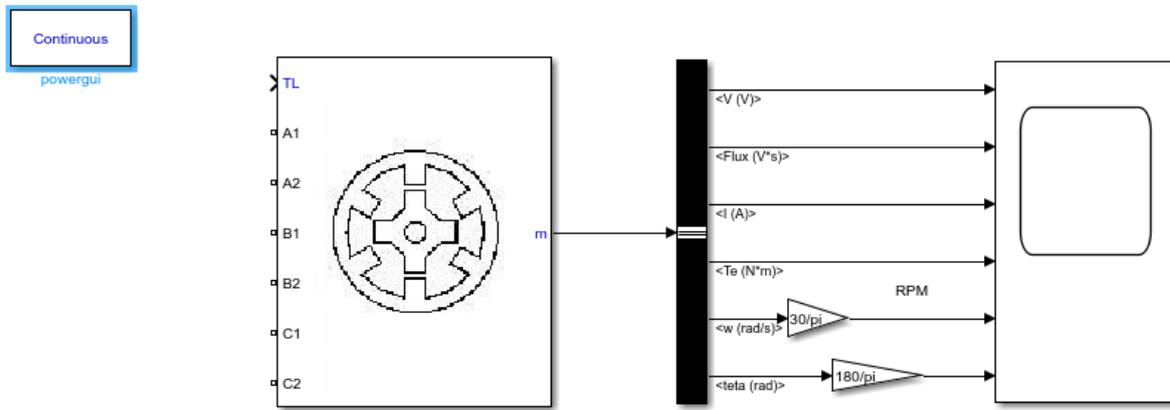


Fig 29: Power GUI Addition

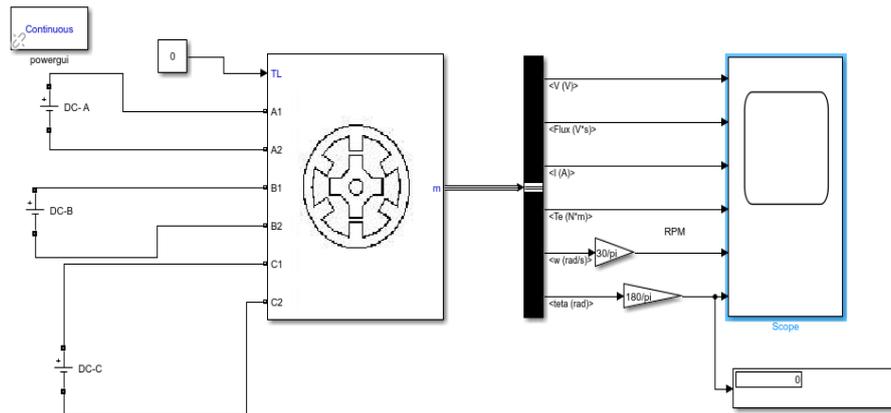


Fig 30: Sample Run

In the sample run , the load torque is 0 , and we have applied the dc current to 1-phase a1 and a2 to full i.e. 200 v and b1,b2 set to 0 and c1,c2 set to 0 and when we check the scope we have the following statistics for current , flux and the total of 6 output signals.

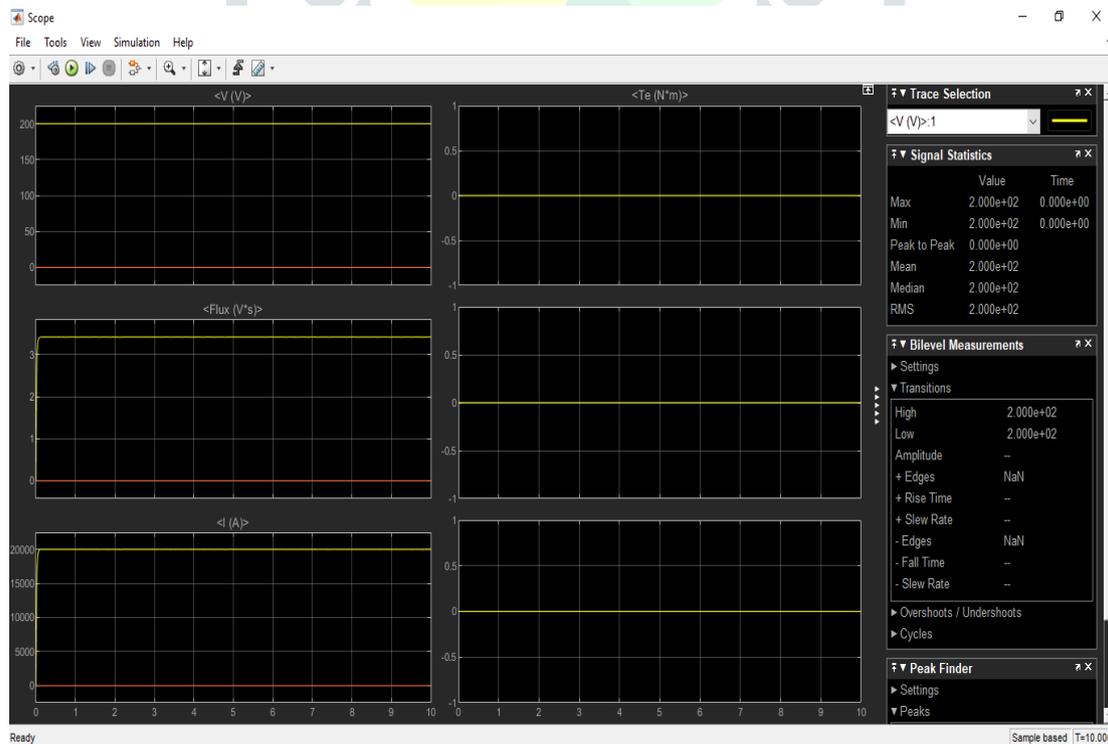


Fig 31: Output Run 1

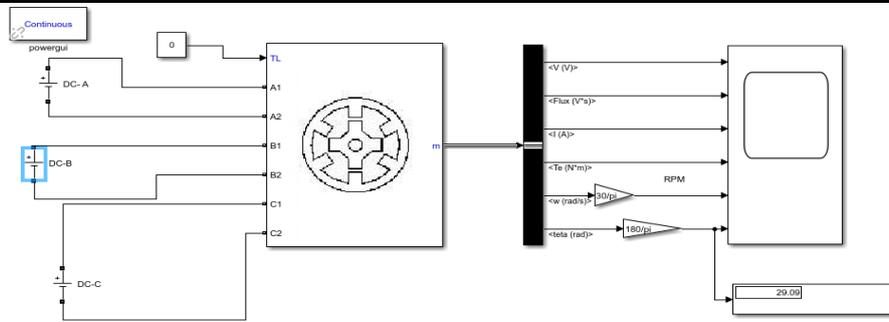


Fig 32: Energizing B-Phase of SRM Motor

In this case the A-phase is set to zero , B-phase is set to 10 and C-phase is set to zero, then the 6 signals on scope will be as shown in Fig 33.

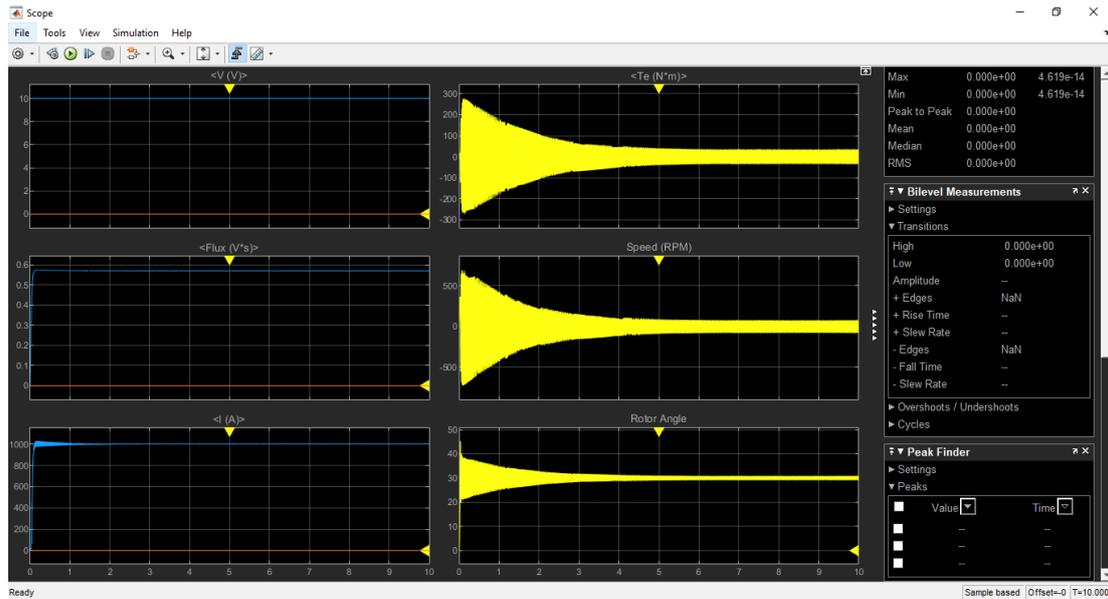


Fig 33: Output Run 2

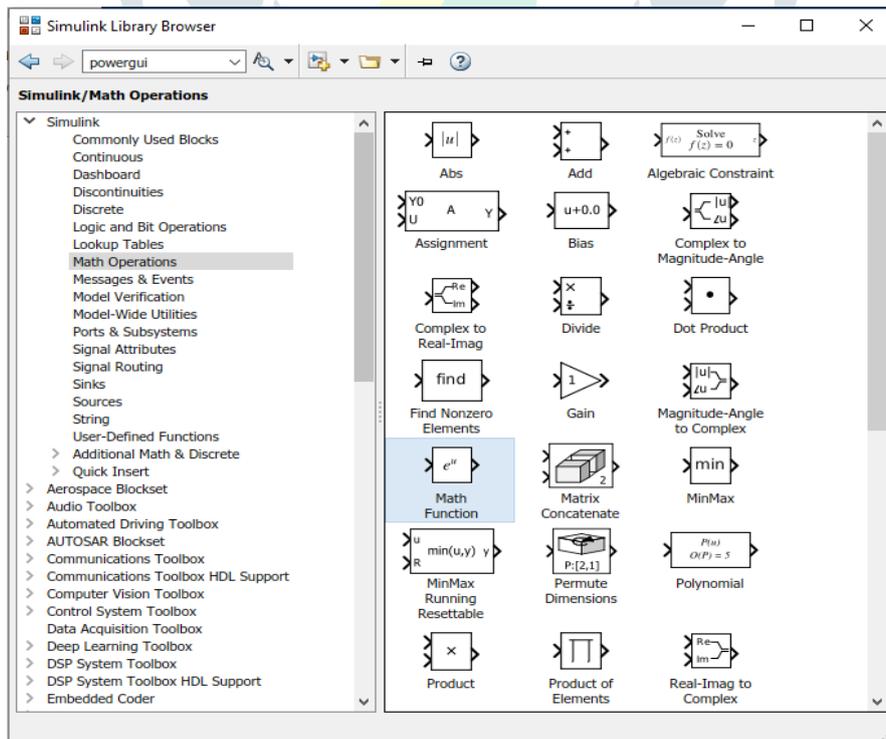


Fig 34: Math Functions

In the fig 34 , library browser is shown for the addition of the Math Function in Simulink for the design of the Commutation Pulse Generation.

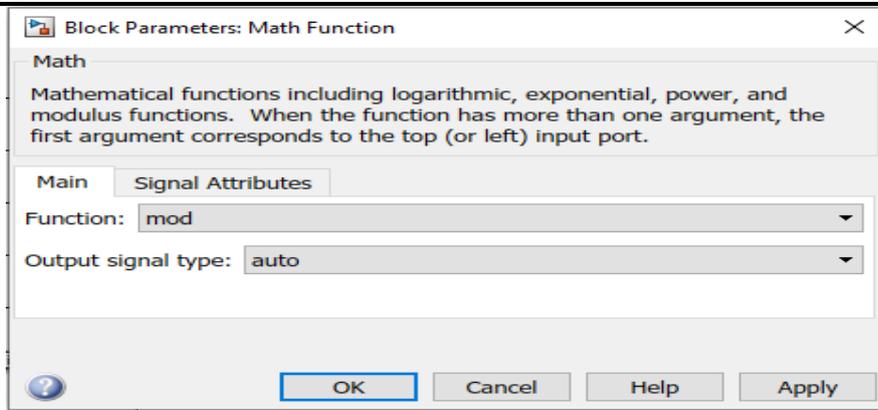


Fig 35: Mod Function Selection

The Math function, mod function is selected for the simulation purpose and the constant = 90 is applied input to it.

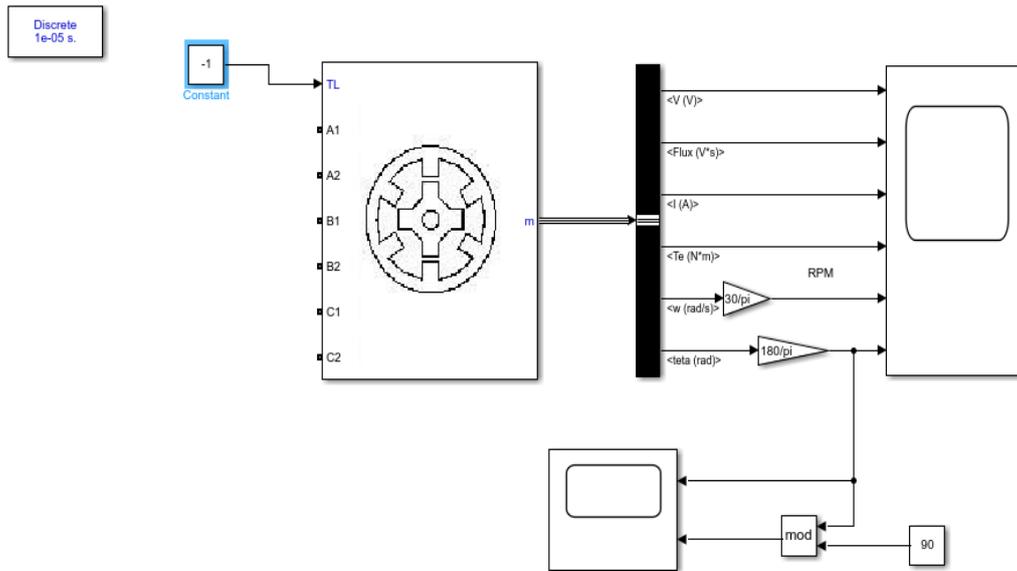


Fig 36: Commutation Pulse Generation

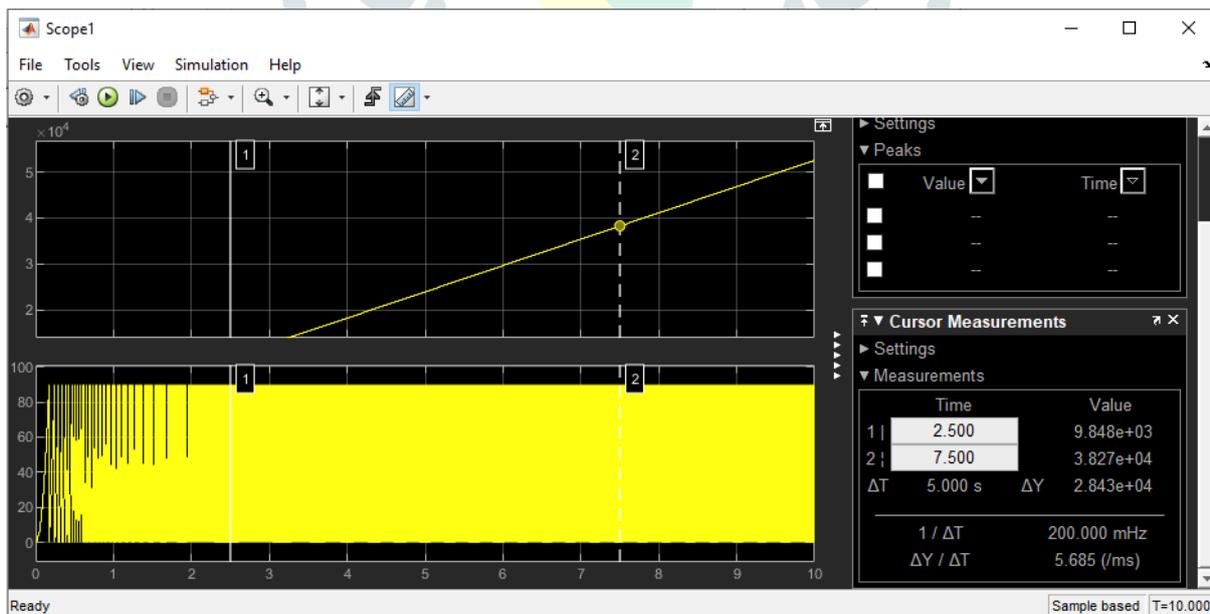


Fig 37: Scope Output Commutation Pulse Generation

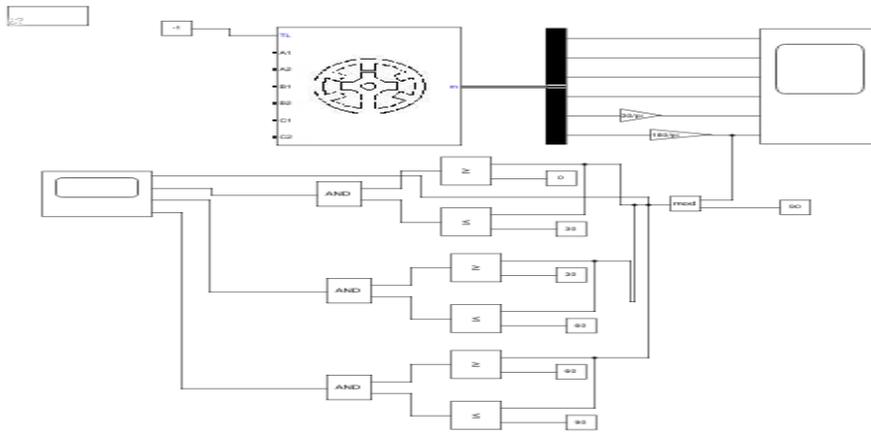


Fig 38: Commutation Pulse Generation with the angle control

In Fig 37, 0 to 30 degree , Phase B , 30 to 60 degree Phase C, and 60 to 90 degree Phase A.

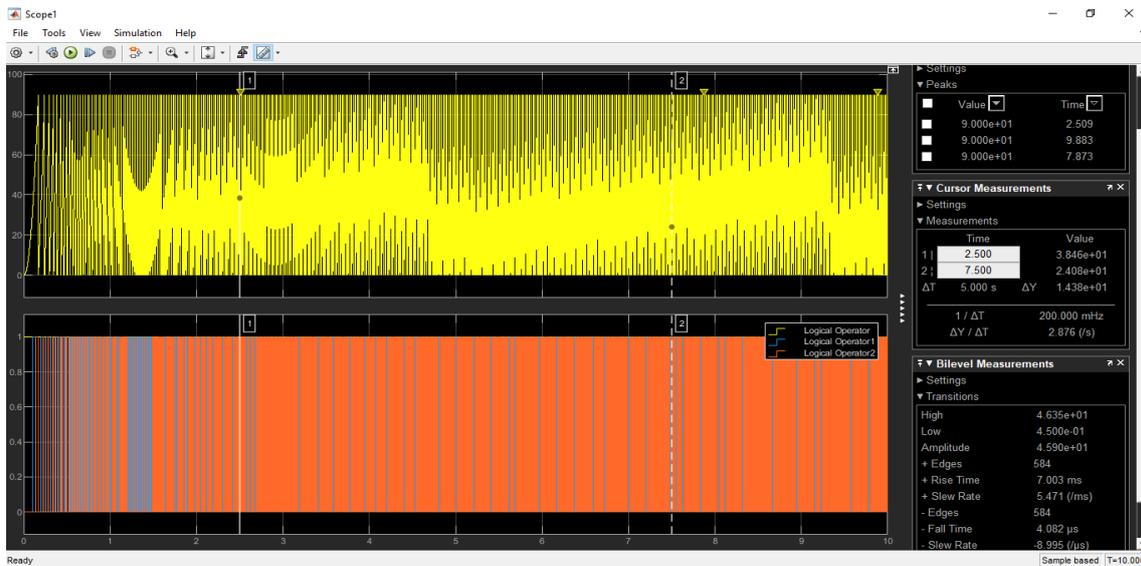


Fig 39: Scope Output Commutation Pulse Generation with Angle Control

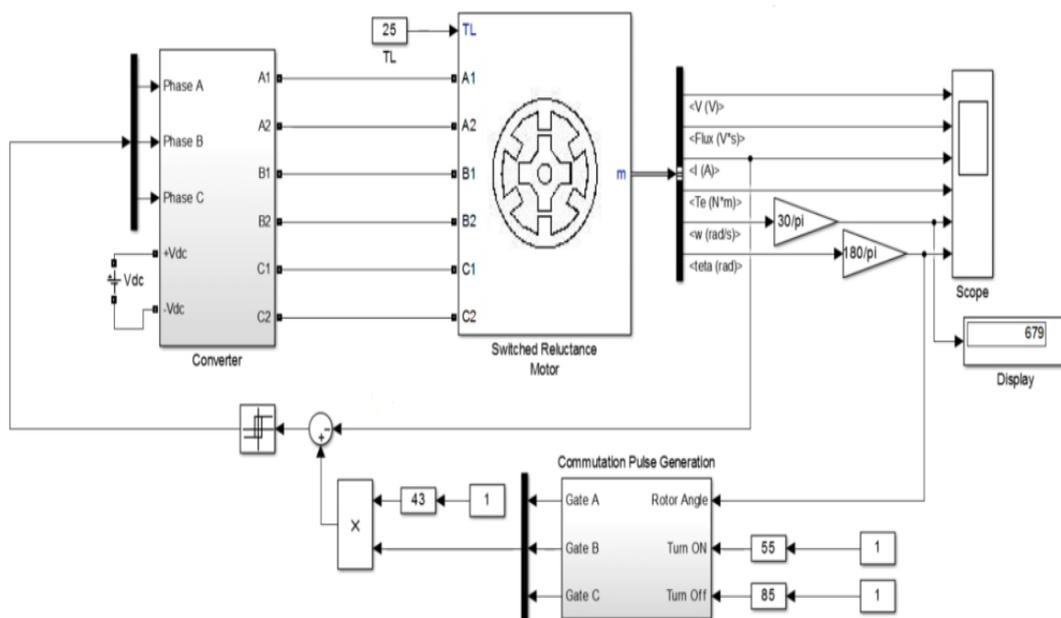


Fig 40 Hysteresis Current Control

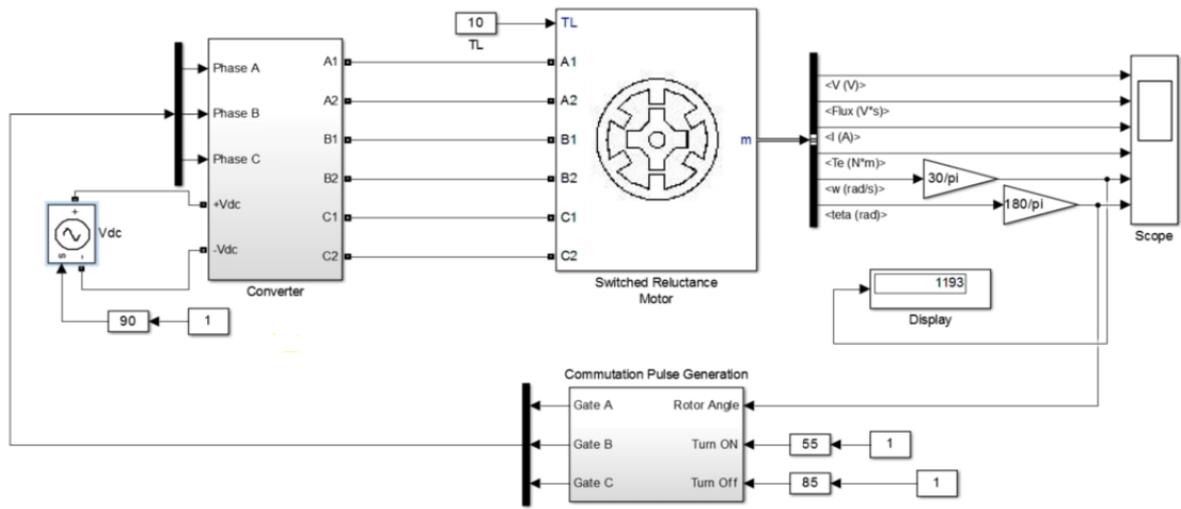


Fig 41: Voltage Control

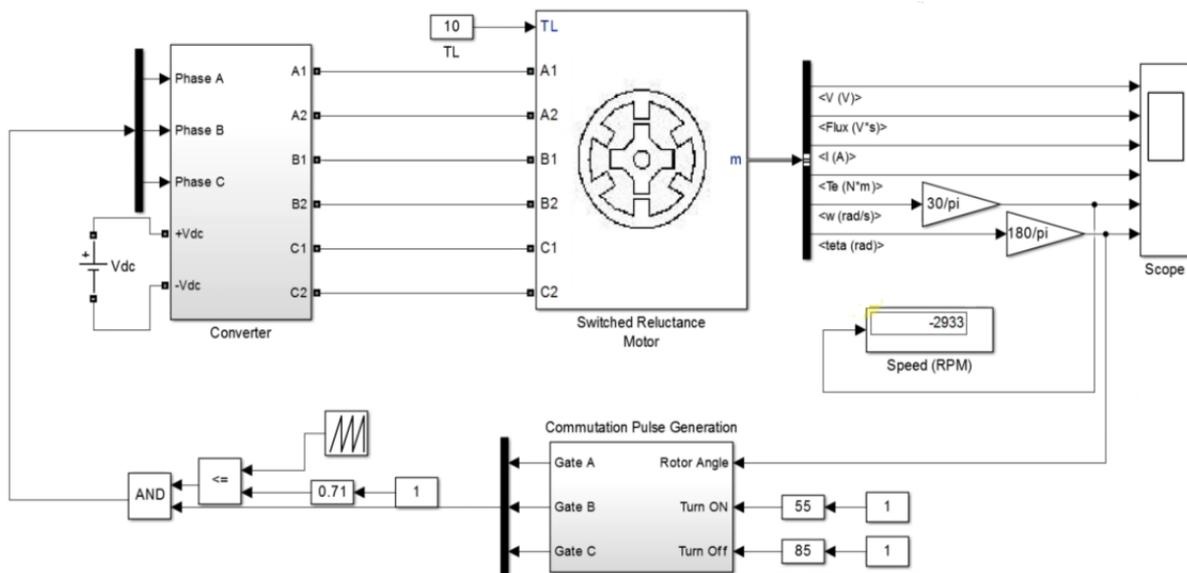


Fig 42: Voltage PWM Control

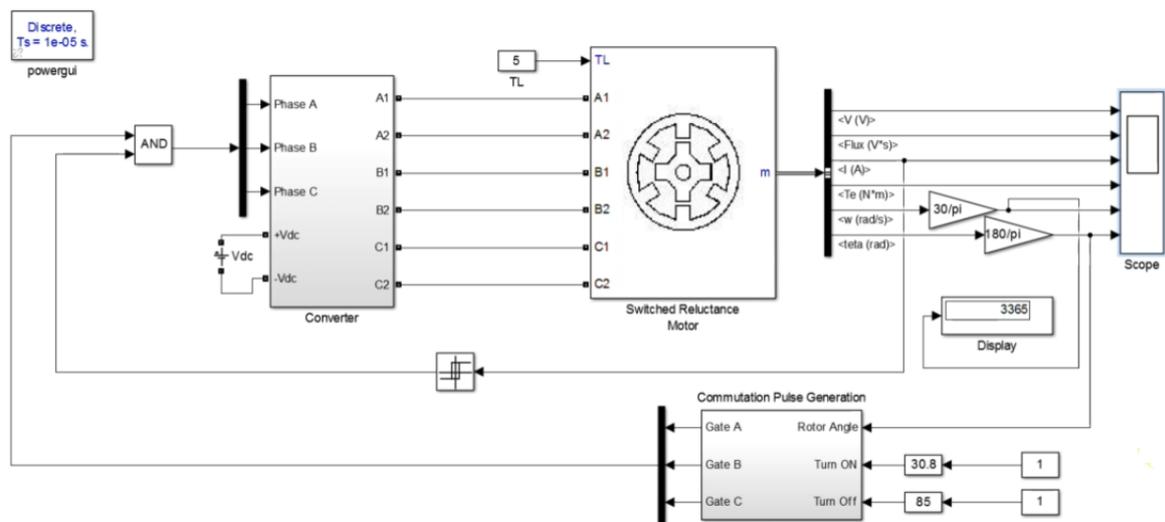


Fig 43: Asymmetric Converter with Current Limiter

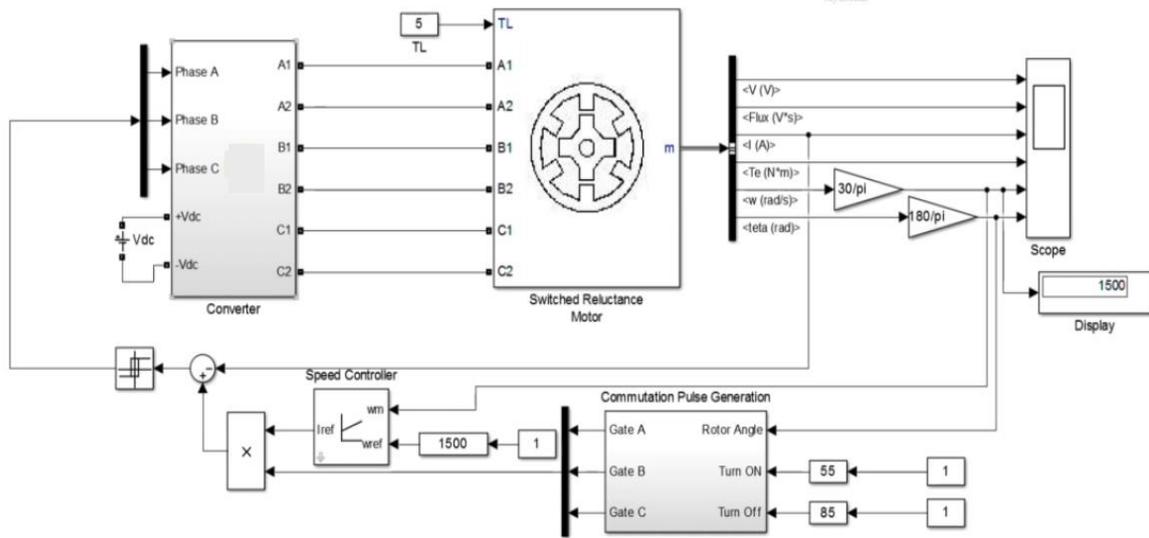


Fig 44: Closed Loop Control Hysteresis Current Control

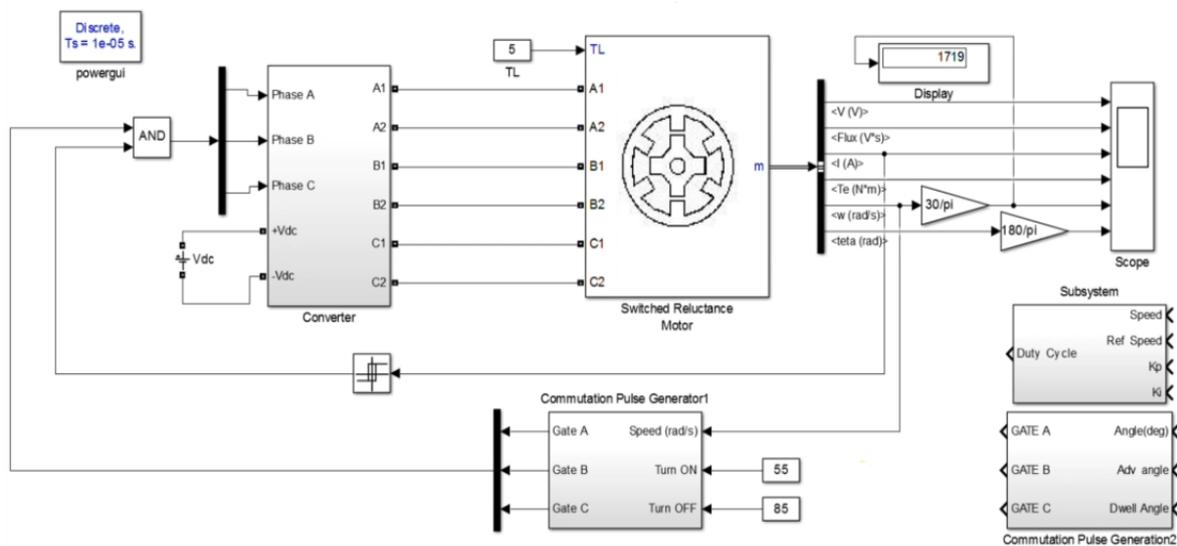


Fig 45: Closed Loop Control with Advance Angle

IV. CONCLUSION

Switched reluctance motor (SRM) is increasing a lot of interest in modern applications, for example, the wind energy based systems and the electric based vehicles because of its basic and tough development, high - speed activity capacity, inhumanity toward high temperature, and its highlights of adaptation to internal failure. Switched Reluctance Motor (SRM) is otherwise called Variable Reluctance Motor. This motor deals with the guideline of variable reluctance. This implies, the rotor consistently attempts to adjust along the most reduced reluctance way. As the name recommends, an exchanging inverter is needed for the activity of Switched Reluctance Motor. Presently, the switched reluctance motor (SRM) is viewed as probably the most ideal choice for working EVs as a result of its focal points of basic structure, ease, high unwavering quality, high force age, and high proficiency at a wide scope of speeds. The immediate and backhanded estimation techniques for SRM attractive attributes are incorporated; examination between the deliberate and determined qualities is accomplished.

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