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DETERMINATION OF BATTERY CAPACITY ACCORDING TO TORQUE-CURRENT CHARACTERISTICS AND SPEED RANGE FOR OPTIMAL BATTERY EFFICIENCY IN ELECTRIC VEHICLE USING SRM MOTOR

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ABSTRACT: This paper presents about the static analyse on usage of the Switched Reluctance Motor (SRM) in the electric vehicle. MATLAB Simulink model of the Switched Reluctance Motor (SRM) with the torque analysis and current analyse for determine the suitable current rating in battery capacity. Also analysing the tractive performance of the motor when it is used in the electric vehicle in terms of the power required to the run the vehicle to determine the optimum running speed of vehicle.

KEYWORDS: Switched Reluctance Motor, Simulation, Tractive Analysis.

INTRODUCTION:

The SWITCHED RELUCTANCE MOTOR (SRM) has a rich history dating back to 1838, but it has truly come into its own in modern times with the advancements in power electronics drivers and computer-aided electromagnetic design. These motors, also referred to as variable reluctance motors, offer a range of desirable qualities found in induction motor drives, DC commutator motor drives, and permanent magnet (PM) brushless DC systems. They are known for their rugged and simple construction, cost-effectiveness, and high peak torque-to-inertia ratios, making them well-suited for high-speed applications. Additionally, their unipolar drive enables simpler and more economical converters. SRMs are proving to be promising low-cost electromechanical energy conversion devices due to their simple mechanical construction, production cost, efficiency, and torque/speed characteristics. As a result, SRMs are increasingly being used in electric vehicles, replacing brushless DC motors and permanent magnet synchronous motors. However, they also present challenges such as range considerations. This paper includes torque and current analyses of SRMs at the initial ignition of the vehicle, as well as determining the optimal speed for electric vehicles to achieve effective range.

SWITCHED RELUCTANCE MOTOR:

Let's consider the 6/4 SRM motor of the rating of the 6kW to make the analysis. i.e., fig1

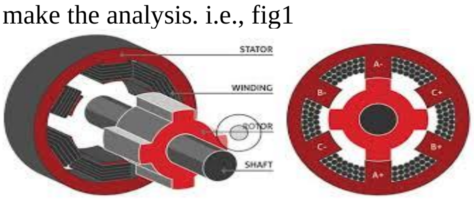

Fig.1 6/4 SRM stator and rotor

As you can see the 6/4 SRM moto will be having the 6 stator poles and 4 rotor poles.

To do tractive analysis on the electric vehicle (electric car) the 6kW motor will be suitable for it rather then going to the higher level of rating motor.

"Magnetic flux has a tendency to flow through lowest reluctance path, therefore rotor always tends to align along the minimum reluctance path." This is the basic working principle of Switched Reluctance Motor or Variable Reluctance Motor.

MATHEMATICAL MODELING OF SRM:

With the assumptions made, an elementary circuit of one SRM phase may be derived as in fig 2a. The sum of the resistance voltage drop and the change rate of flux linkage must be equal to the applied voltage to a motor phase; thus Eq. (1) can be derived, where V is the voltage applied to the phase, I is the phase current, R is the phase resistance, λ is the phase flux linkage, θ is the rotor position, and e is the back electromotive force.

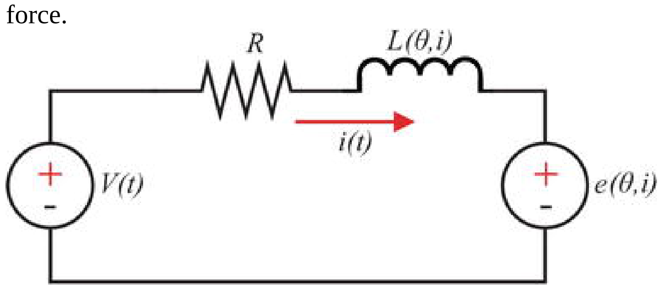

Fig.2a

The flux linkage is

$\lambda(\theta) = L(\theta)i$ ……………………………………….. (1)

The flux linkage is denoted by λ, and the independent input variable, i, represents the current flowing through the stator winding. The general torque expression is given as:

$Te = [\partial W']/\partial\theta]i$…………………………………. (2)
The co-energy varies based on the position of the rotor. The co-energy is the area below the magnetization curve, as illustrated in Figures 3 and 4. The definite integral below represents stored magnetic energy.

$w' = \int_0^i \lambda(\theta, i)di$………………………………….. (3)
λ (θ, i) represents the flux linkage between angular position θ and current 'i'. Thus, the torque equation becomes:

$Te = [\left[\int_0^i \partial\lambda(\theta,i)di\right]/\partial\theta]\ di$……………………… (4)

The mechanical work done is

$\Delta Wm = \Delta W'$…………………………….………(5)

Wm represents mechanical energy, while W' represents stored magnetic energy. At any rotor position θ, the co-energy and stored field energy are equal, as shown by

$Wf = W' = \frac{1}{2}L(\theta)i^2$ ...…………………………… (6)

The instantaneous torque reduces to

$Te = \frac{1}{2}i^2\ \partial L/\partial\theta$………………………………...…. (7)
In multiphase SRM, the torque equation combines torques from each phase. The total torque for m phases can be calculated as
$Te = \sum_{j=1}^{m} T_{ej}$…………………………………..…..(8)
Where Tej is the torque due to single phase.

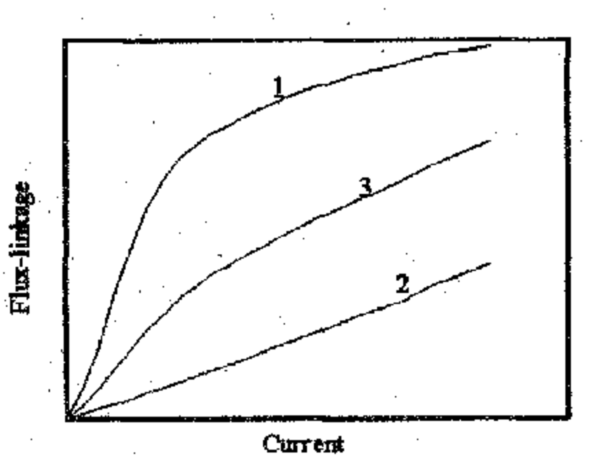

Fig. 2 Flux-linkage characteristics of SRM at different rotor positions.
Fig.2b

TORQUE-CURRENT CHARECTERISTICS:

BLOCK DIAGRAM OF SRM CONTROL:

The rotor position sensor senses the rotor's position and sends the error detector the corresponding output. An error signal is generated by the error detector and sent to the controller block after a comparison between the reference and actual speeds. In accordance with the error signal, the controller sends the converter the proper control signal. The converter regulates the motor's speed by appropriately exciting the relevant windings in the stator. As given in fig 3

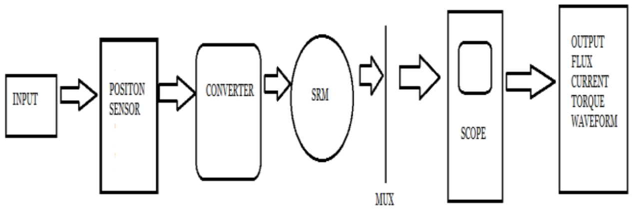

Fig.3 BLOCK DIAGRAM

MATLAB SIMULINK MODELLING:

Figure 4 shows the MATLAB Simulink modelling of the 6/4 SRM configuration

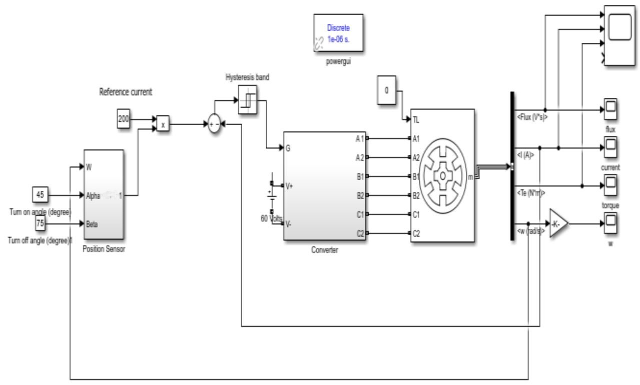

Fig.4 MATLAB CONNECTION

SRM CONFIGURATIONS:

There are various configurations for switched reluctance motors, including 12/8, 8/6, 6/4, and 4/2. However, 6/4 arrangement is the focus of this discussion. In this, the rotor has two-pole pairs while the stator has three-pole pairs. Another name for it is 3-phase SRM. A three-leg, three-phase, asymmetrical power converter that has two IGBTs and two freewheeling diodes on each leg supplies power to the SRM. In order to induce positive currents into the phase windings during conduction periods, the active IGBTSs apply positive source voltage to the stator windings. Negative voltage is applied to the windings during free-wheeling times, and the diodes allow the stored energy to be restored to the power DC source. This method can reduce the duration of current decay in motor windings. The precise turn-on and turn-off angles for the motor phases can be dictated through a position sensor attached to the rotor. By altering these switching angles, the torque waveforms generated can be modulated. The hysteresis band is the main factor that defines the switching frequency of the IGBTs.

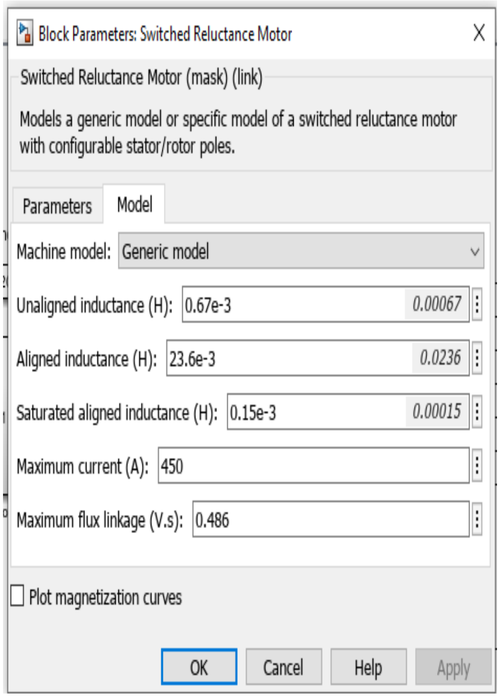

Fig.5a

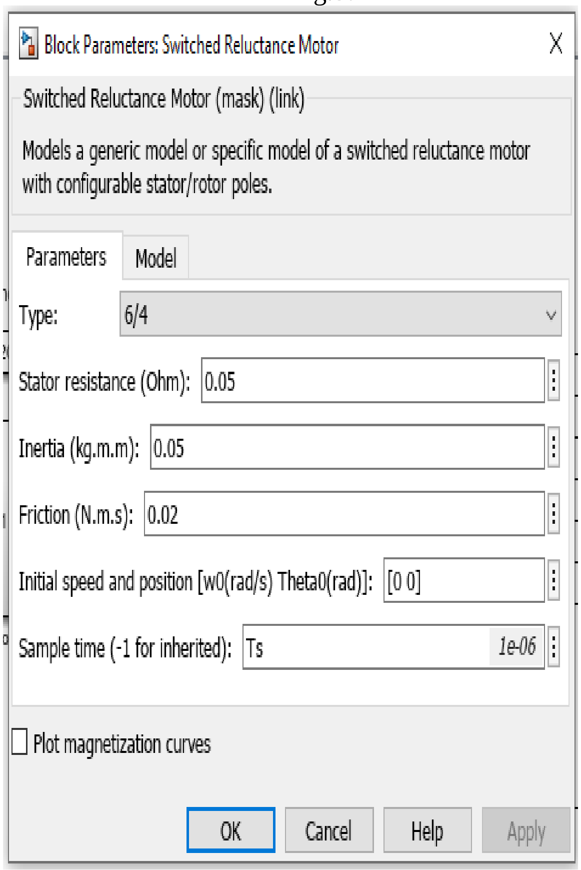

Fig.5b

Fig.5 RELUCTANCE PARAMETER

SIMULATION OF 6/4 MODEL:

A 240V DC supply voltage is employed. Over the speed ranges, the converter's turn-on and turn-off angles remain constant at 45° and 75°, respectively. A 200A reference current and a ±10A hysteresis band are selected. Applying the step reference to the regulator input initiates the SRM. The properties of the load determine the acceleration rate. A very light load is selected in order to reduce the start-up time. Because the motor speed is only regulated by the currents, it will grow in accordance with the system's mechanical dynamics. The following illustrates how the SRM drive waveforms phase voltages, magnetic flux, windings current, motor torque, and speed appear on the scope.

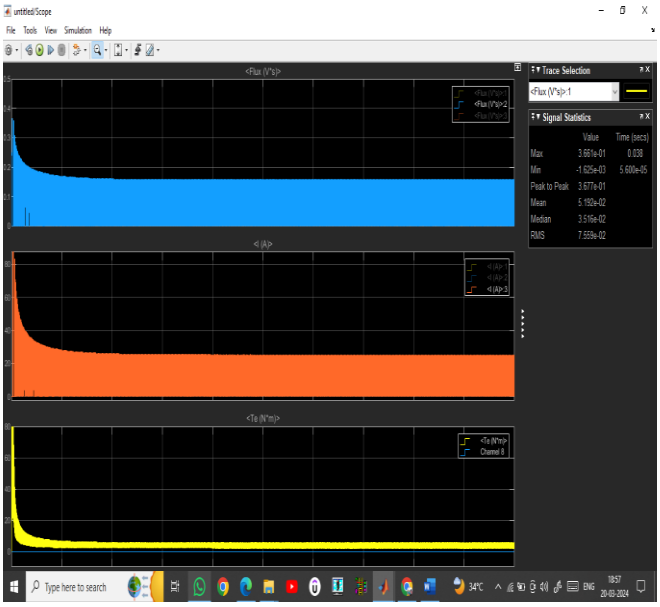

Fig.6 SIMULATION OUTPUT

It is evident that the SRM exhibits a significantly elevated torque ripple component, which can be attributed to the currents shifting from one phase to the next. The key factors influencing this torque ripple, which is unique to the SRM, are the turn-on and turn-off angles of the converter. Upon examining the waveforms of the drive, by observing that the SRM operation speed range is bifurcated into two regions based on the converter operating mode: voltage-fed and current-controlled.

DISSECTION OF THE MATLAB-SPECIFIC SWITCHED RELUCTANCE MOTOR MODEL

Position sensor:

Fig.7 POSITION SENSOR

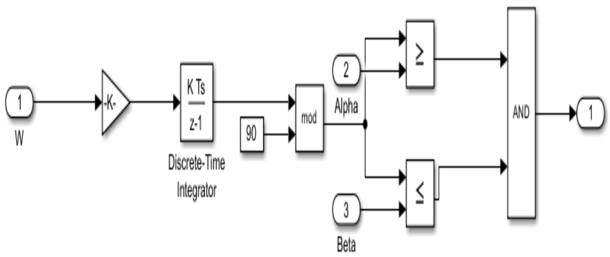

Fig.8 POSITION SENSOR CIRCUIT

Motor drive:

When it's given the DC voltage from the battery source to the motor drive, it converts the DC voltage to the AC three phase voltage. By using the power converters such as H bridge converter.

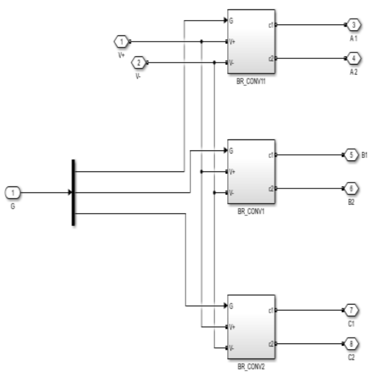

Fig.9 MOTOR DRIVE CIRCUIT

CURRENT REQUIREMENT:

As observing from the MATLAB Simulink, the initial torque required by the mote is quite high as nearly reaches 100 newton-meter so as the toque gets higher the current requirement is also getting increased as much as 120 ampere and even higher.

So, by taking this into the consideration its necessary to make the battery for electric vehicle by taking consideration for the battery capacity as it meets the current requirement to get the initial torque.

OPTIMAL SPEED DETERMINATION:

TRACTIVE ANALYSIS:

For the tractive analysis of the vehicle its need to go with the basic kinematic to find the acceleration that desired followed by the force needed to make the vehicle move in that acceleration so that from the force required it can be converted the power needed by the motor to provide the rotation force in order to make vehicle move.

Mass of vehicle = M ……………………………...(kg)

Distance needed to be covered = D ………….……(m)

Desired time to cover the distance = T……………...(s)

Velocity required V = D/T………………………(m/s)

Initial condition:

Acceleration needed to make the vehicle to be moved the required velocity

A= D/t

t= time to attain the velocity

Force needed to move the vehicle from rest to the required velocity, usually this force would be higher since the initial velocity is zero i.e., rest.

Force required= M x A

And to convert the force in terms of power requirement, multiply the force with the average velocity.

Power required= F x (average velocity) ………….. (9)

By analysing this with various time the outcome will be various power requirement. The power requirement is inversely proportional to the Time taken.

TRANSMISSION ANALYSIS ON RESISTIVE FORCES:

On the ideal an analysis condition the velocity won't be chance so the average velocity would be zero so the power requirement would also become zero.

But in the practical cases there would be lot of opposing forces would be present which reduces the vehicle running speed such as frictional force, aerodynamic force etc.,

So, in order to maintain the vehicle at the constant speed its certain to accelerate the vehicle in order to overcome the retardation, so the force for moving the vehicle would also be equal to the opposing forces.

There are many types of opposing force also called as resistances for the vehicle, but three opposing forces plays the majority of role in this case.

Those resistance are:

- Rolling resistance
- Aerodynamic drag
- Gradient resistance

ROLLING RESISTANCE:

The rolling resistance also known as frictional force between the tyre and road is the unavoidable in any condition and approximately constant through the journey is the road type is same.

It is the frictional force acting between the tyre and the road. It may vary on depending the different types of roads, different kinds of types and even the environment conditions. i.e., the frictional force between the tyre and the road will be lesser than normal when the road is wet, so this Is the reason behind the slippery in vehicle when it rains.

To find the frictional force between the road and tyre, primarily need is that tyre characteristic from the manufactures, in which they will provide with the coefficient of friction.

Rolling resistance = (coefficient of friction) x (mass) x (acceleration)…………. (10)

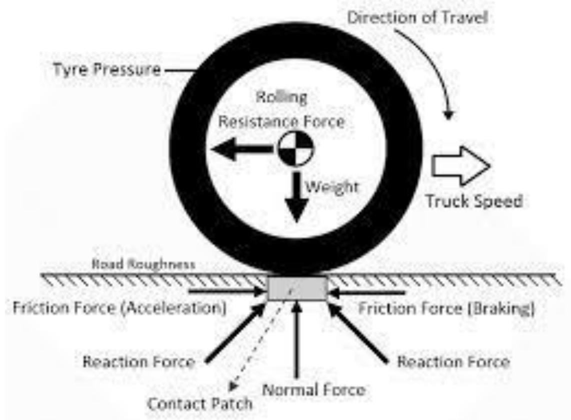

Fig.10 FORCE ON TYRE

AERODYNAMIC DRAG:

Aerodynamic drag also called as the Aerodynamic resistance is the resistance which will play roles when the vehicle speeds up so that the opposing wind speed of the vehicle will be increasing, as the relative velocity between the wind and vehicle increases the opposing force of the wind will also be increases.

The aerodynamic resistance can be reduced by making the optimal design of the vehicle which should be effective for the reducing the air drag.

To find the aerodynamic drag:

Aerodynamic resistance = 0.5 x (density of air) x (cross sectional area) x (coefficient of air drag) x (velocity ^{2}) ………… (11)

from the equation its clearly understand that the aerodynamic drag is mainly depend on the cross-sectional area and the velocity of the vehicle

the cross-sectional area of the vehicle would be the cross-section area from the front side which means the surface area of the vehicle which stand against the wind flow. Usually the cross-sectional area of the car will be around 1.5 to 3 sq. meters.

On the other hand, the important deciding factor will be the velocity, as you see the aerodynamic drag will be directionally proportional to the square of the velocity until certain velocity the aerodynamic drag won't be much higher but after certain limit the aerodynamic drag will be increasing exponentially so its certain to take account of it.

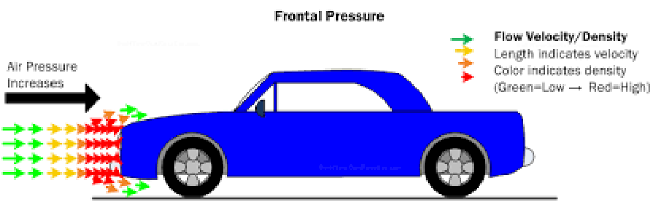

Fig.11 AERODYNAMIC DRAG

GRADIENT RESISTANCE:

The gradient resistance is the opposing force which will occurs when the vehicle climbs trough the slope area. It is basically the gravitational force but the y component of the gravity.

The gradient force will be larger than the other two forces.

Gradient resistance = (mass) x (acceleration due to Gravity) x (sinθ) …………. (12)

$\theta = angle\ of\ inclination$

The gravity* sinθ denotes the y axis component of the gravity field.

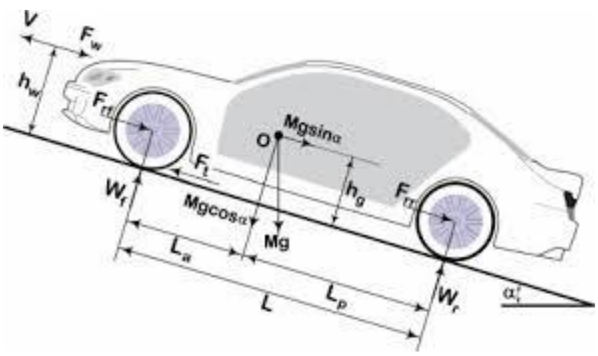

Fig.12 GRADIENT FORCE

In addition to these forces there are many other forces which reduces the velocity of the vehicle. But these three plays the major role in transmission analysis.

ANALYSIS ON THE DIFFERENT CONDITION:

Mass of vehicle is 285 kg

Velocity required is 60 kmph

The power required chart for to attain the different velocity in the desired time (t)

Desired time(t)= 15 s

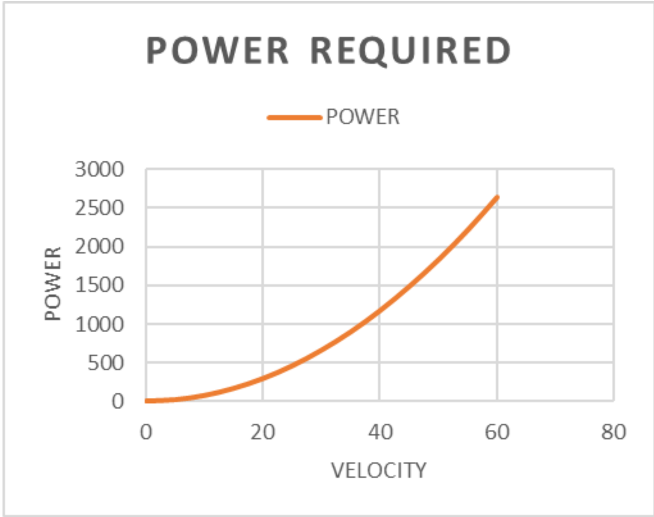

Fig.13

By observe the above graph in fig14, the power required to reach the desired velocity at the defined time (t) is determined.

At running condition:

On the non-incline road only rolling resistance and aerodynamic drag only occur. In the incline all above mentioned three forces will act.

The aerodynamic will change with respect to the velocity.

Let's analyse on different running condition as follows:

- On non-inclined road.
- On inclined road
- On non-inclined wet road.
- On inclined wet road.

ON NON-INCLINED ROAD:

In the non-inclined road, the opposing forces act are the rolling resistance and aerodynamic resistance. Here given the analysed graph plot between the power required vs velocity of vehicle in fig15

Let's assume

Coefficient of rolling resistance = 0.08

Cross sectional area = 1.3 sq. meter

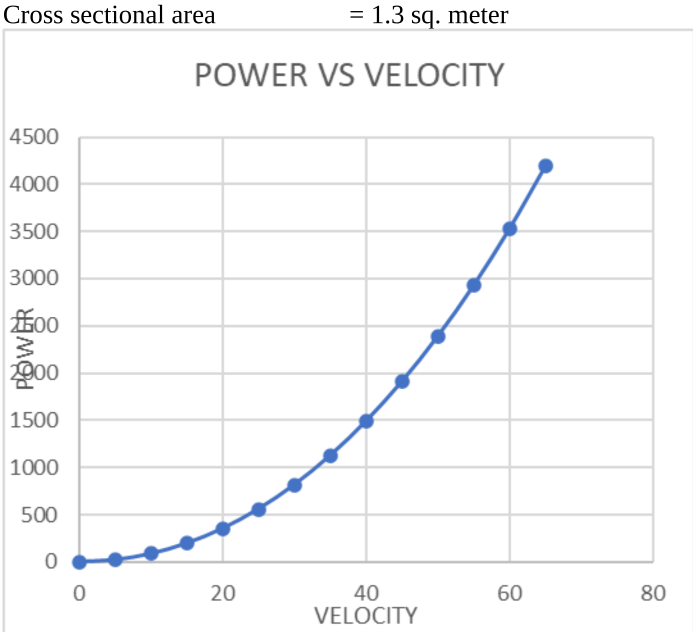

Fig.14

ON THE INCLINED ROAD:

In the inclined road all the three forces will act together results in the greater power requirement.

Let's assume

Coefficient of rolling resistance = 0.08

Cross sectional area = 1.3 sq. meter
Angle of inclination = 5°

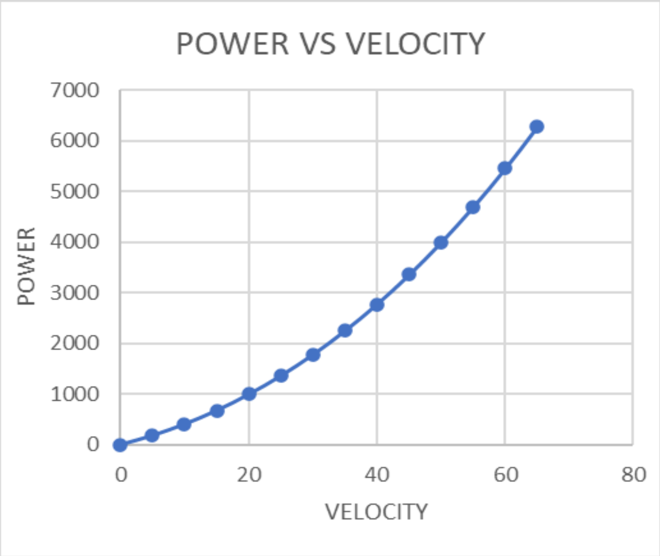

Fig.15

ON THE NON-INCLINED WET ROAD:
In the non-inclined road wet road, the coefficient of friction would be lesser than the normal road since it has less friction between road and tyre.
Where
Let's assume
Coefficient of rolling resistance = 0.04
Cross sectional area = 1.3 sq. meter

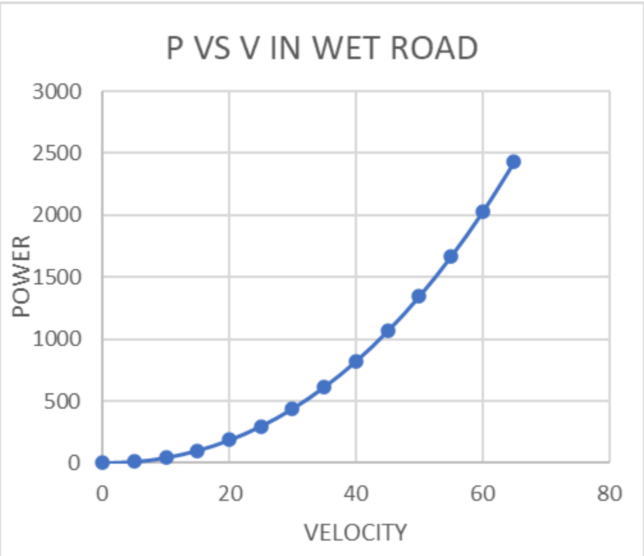

Fig.16

ON THE INCLINED WET ROAD:
In the inclined wet road all the three forces will act together results in the greater power requirement.
Where
Let's assume
Coefficient of rolling resistance = 0.04
Cross sectional area = 1.3 sq. meter
Angle of inclination = 5°

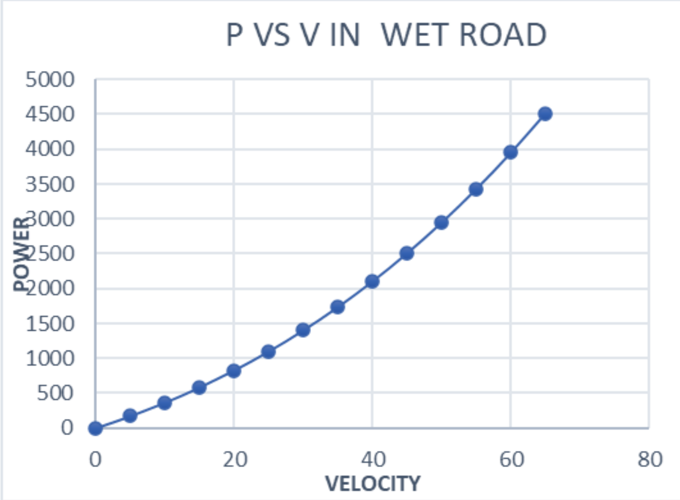

Fig.17

COMPARATIVE ANALYSES:

Comparative analysis on the both cases of the both normal road and wet road shows that the impact in power requirement by the gradient resistance.

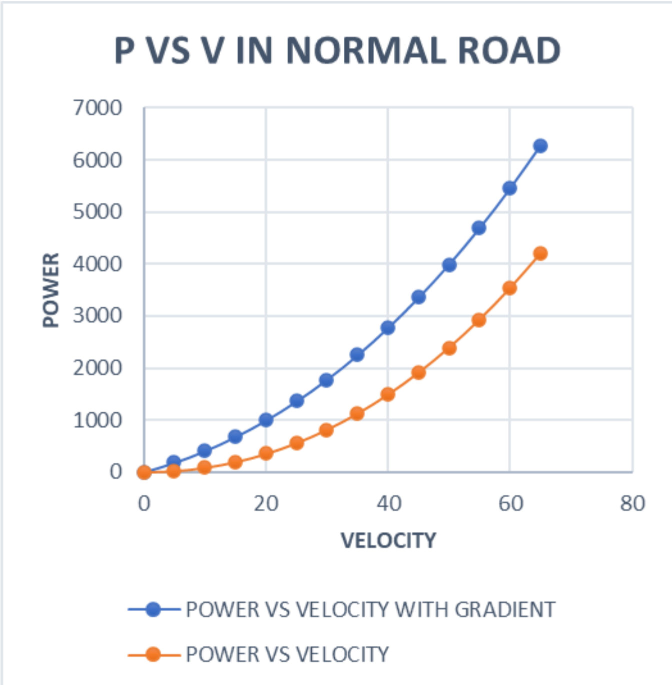

Fig.18

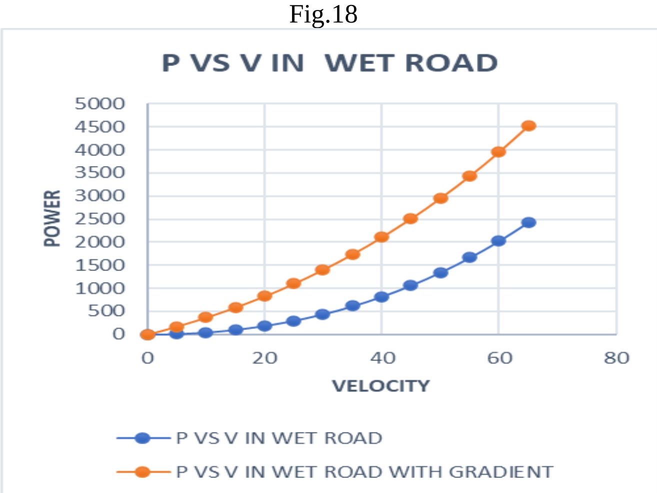

Fig.19

OPTIMAL SPEED:

As doing analyses from the above graph it can conclude the optimal speed of the vehicle. By observing the graph of the non-incline road condition, when the velocity is in the range of 40-50 in both case the change in power becomes ≤ 1000 W so I consider this would be an optimal driving speed when considered both range and time consideration.

And similarly, when analysing in the gradient case, its observed that the velocity range as 20-30 would be optimal driving speed.

CONCLUSION:

In this paper, the MATLAB Simulink model of the Switched Reluctance Model for torque and current characteristics is taken. The initial torque of the motor is the main component which gives the initial momentum for the electric vehicle and in order to attain that torque level it needed the respective current value so our battery for the electric vehicle should have the capability of serving those current.

The optimal range for the electric vehicle is determined by using the static transmission analyses, but however it will change with different type of vehicle model. Here the example for substituting data to find the optimal speed of vehicle is given in same way to find the optimal value by substituting data of the respective design model.

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