

# Fuzzy Logic Power Drive and Regenerative Breaking for HEV

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**Abstract –** Speed-limiting and stopping of the vehicle constitutes to loss of energy which was put in to reach the running speed. This loss in energy results in consumption of extra fuel. The wheels then generated mechanical energy is enough that it can be trapped into a battery after conversion. Thus, stored energy can be used to assist the HEV during running on fuel. The battery energy pushes and assists the HEV during takeoff and during gear changes. Fuzzy Logic plays a role in making and braking of electrical power transfer to the battery. Switching arrangement functions to switch the power train on the wheels from motors or the engine.

**Keywords—** Internal Combustion Engine, HEV, Engine control loop, Regenerative Breaking, Fuzzy Logic, BLDC Hub Motor.

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## 1. INTRODUCTION

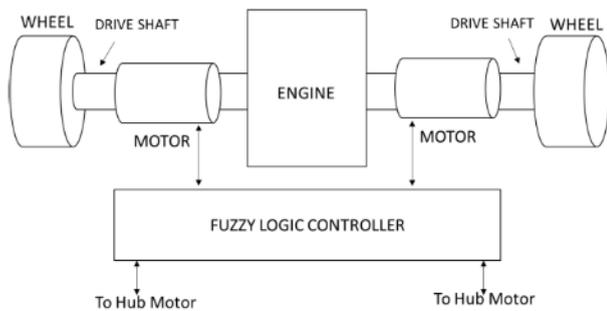
Hybrid Electric Vehicle (HEV) design is divided into two types. Series Hybrid and Parallel Hybrid. Generally, a vehicle is designed to be one of the two types. Each is unique for the application it is used for. Any of these two needs a braking system. The motors used for driving the powertrain can be used as regenerative braking along with frictional braking system. Electric motors are configured as electrical power generators to charge a dedicated drained battery. Vehicle mass plays a role in amount of energy generation. The braking system of the vehicle performs four unique need. Brings the vehicle to a halt in a short distance. Delivers a distributed control on all the wheels of the vehicle. Keeps the battery drained for the next energy capture from the wheels. Regenerative braking applies engine retarding function as in Internal Combustion Engine vehicles which is a need during rolling the vehicle downhill.

A logical switching and control of the motor as generator takes place in two ways. One is power delivering on to the wheels and the other is power extraction from the wheels. Amount of power delivering, and power draw depends on various conditions of the vehicle (Chen, et. al., 2003). A dedicated Fuzzy Logic is developed to cater these demands. Apart from these needs, a safety in braking is in culture of vehicles these days. Safety is

achieved through Anti-Lock Braking (ABS). This is achieved through logical operation of make and break of electrical connectivity of the generator to the drained battery. Battery operates as a load which in turn puts a calibrated load on the running wheels. Power train battery bank is used to store energy from charging sources and while on the go through the battery employed to capture regenerative braking. Fuzzy Logic controller functions to operate the motors to run the wheels assisting the engine and for braking the speed or halting. This constitutes to saving of fuel to a large extent.

## II. ENGINE AND MOTOR INTEGRATION

Most of the vehicles are front wheel drive. Engine drives the wheels through a gear box. Rear wheels are a drag and support for braking in engine driven vehicles. This concept employs a motor drive parallel to the drive shafts on the front wheels. Rear wheels are hub motors.



**Figure 1, Engine and Motor Coupling**

The engine with gear box has drive shafts on each of two front wheels. The engine takes the wheel load during gear is engaged from 1<sup>st</sup> to 5<sup>th</sup>. In neutral the wheels are free to rotate. As shown in fig.1, Motors are mounted on the drive shafts. This coupling makes the wheels rotatable by the engine, by the motor and both. When engine or motor rotates the wheel, it is called as series hybrid. When engine and motor rotate the wheel sharing the load in ratio, it is called parallel hybrid. Fuzzy Logic controller decides to operate in series hybrid or Parallel hybrid mode. Rule base is formed to decide the operation mode. In regenerative braking, motors are switched to operate as generators. Brake pedal pressure decides the amount of current to be transferred from the generator to the battery. This also decides amount of braking on the wheels.

### III. POWER HANDLING ON WHEELS

In HEV generally it is a front wheel drive. Rear wheels usually roll. This is a proposal for rear wheel drive along with front wheel drive. Rear wheel drive helps in regenerative braking which pours all the possible power capture from the vehicle (Chibulka, 2009). As indicated in Fig.1 Fuzzy Logic Controller extends its control on to the rear hub motors. In both front and rear wheels electric motors are turned ON and OFF. In between ON and OFF power deliver and draw at the wheels electric power is regulated depending on the terrine demand. While the power is needed at the wheels, engine is assisted with required power on to the wheels. Operation of motors as power assistants and regenerative braking are as following.

#### 1. Series Hybrid HEV

In this mode, the vehicle is transferred into Neutral mode and Engine works as battery charger as well as electrical power source to the motors. Vehicle is carried on traction consuming fuel to charge the battery. In turn using battery power for the run of vehicle. Wheels are loaded resulting in cutting speed and further extending to a halt. In this mode terrine demands are carried by the motors were engine undergoes a capacitive loading.

While it is operated as regenerative braking, the motors are linearly switched to charge the battery.

Such captured energy is stored in battery bank. Amount of capture and amount of impeding the vehicle from running is decided by the amount of press of brake pedal. These decisions are taken by the fuzzy logic controller.

#### 2. Parallel Hybrid HEV

In this mode the vehicle takes off on engine and motors turn ON when there is shortfall of engine capacity. The engine drive and electric drive operate simultaneously. In conditions they go in phase and out of phase. Engine carries the wheels continuously but Motor Intervenes to dispense quick power needs to the wheels avoiding the engine to react to the terrine conditions (Cheong, 2013). The sensors keep a track of power draw from the wheels and proact to the sudden changes and needs of power to deliver from motor. Another such condition is during take-off, Idling condition and run in downhill.

In this mode while braking the motors are switched to behave generator and linearly operated to fall a load on the wheels. Such capture and amount of impeding the vehicle from running is decided by the amount of press of brake pedal. These decisions are taken by the fuzzy logic controller.

#### 3. Series and Parallel Hybrid HEV

This is a mode were the vehicle is operated in Series Hybrid and Parallel Hybrid. The change over takes place on the Go. During Take-off the system is put in Series mode were battery gets charged and vehicle is moved on motor. While at idling condition the engine is employed to charge the battery. Once the battery is fully charged, then the engine is turned off. While the vehicle is running on engine, the motor is gradually put to Parallel Hybrid condition and starts assisting the engine. The sensors keep a track of power draw from the wheels and proact to the sudden changes and needs of power to deliver from motor.

During braking the motor is put to series operation and speed of vehicle is reduced. During this condition once there is a need of heavy braking, the parallel operation is brought to connectivity. Further need of braking puts the vehicle to operate friction brakes. Fuzzy logic plays a vital role in deciding series and parallel operation as well as amount of applying the brakes to draw power from the wheels. This part of the system will be talked in a separate paper with the name Smart Redundant Electronic Energy Delivery Electric Vehicle Interface.

### IV. SENSORS AND ACTUATORS

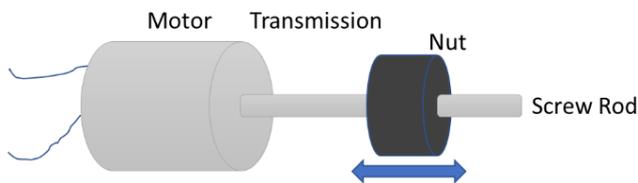
To operate the vehicle as HEV apart from the drive train, parameter sensing and actuators to shift gears and operate friction brakes are required.

**Sensors:**

The vehicle sensor parameters are available on a dedicated CAN bus which is converted to On Board Diagnosis (OBD) available in any engine driven vehicle. For HEV interface on a vehicle, following readings are required from the OBD. Speed, RPM, Gear level, brake pedal position, Accelerator pedal position, fuel consumption per hour and Power delivered to the wheels.

**Actuators:**

Apart from the motors coupled to the drive shafts, an actuator required to assist is friction brake. This is needed in emergency stop and while parking the vehicle. This is a micro motor actuated mechanical screw rod arrangement to operate hydraulic master cylinder unit.



**Figure 2, Motorised Screw Rod Mechanism**

Fig.2 indicates the Motor coupling and the mechanism to drive the brake master cylinder. Transmission coupling is mounted on the shaft and the screw rod which drive rotates the screw rod in forward or reverse directions. Motor is mounted on a fixed base with a reference (Clegg, 1996). The nut mounted on the screw rod is hooked to the lever of the brake master cylinder. When the motor is energised starts rotating the screw rod and in turn swipes the nut in a particular direction. This action is illustrated in Fig.2 in arrow marks.

**V. APPLICATIONS**

This is proposed to interface into any vehicle driven on Petrol or Diesel. In any one the motors can be configured to operate as series hybrid or parallel hybrid. This is an add-on to existing vehicles. Application can be made with front wheel drive and rear wheel drive vehicles. On front wheel drive vehicles, rear wheels can be built up with a hub motor. This adds power and adds powerful braking and regenerative braking. Smaller vehicles do need front drive shaft mounting and rear hub motor for better regenerative braking. Observations have shown that this performs better in small vehicles when operated in series hybrid configuration. This concept avoids flywheel which functions to smoothen the rotational motion of the engine. Flywheel otherwise consumes energy to power push the shaft[4].

**VI. FUZZYFICATION AND DEFUZZIFICATION**

This is a representation for regenerative braking. Brake pedal position is read, and the motor is configured to operate and generator. The generator power delivered is applied onto a drained battery. The power pulse delivered from the generator is subjected on to the battery. The quantity of power pulse to be delivered on to the battery is decided by the brake pedal sensor.

**Brake Pedal Position**

SS – Small

MS – Medium

LS – Large

{SS, MS, LS}

**Wheel speed**

SR – Small RPM

MR – Medium RPM

LR – Large RPM

{SR, MR, LR}

**Regenerative Voltage:**

VS – Very Small

S – Small

M – Medium

L – Large

VL – Very Large

{VS, S, M, L, VL}

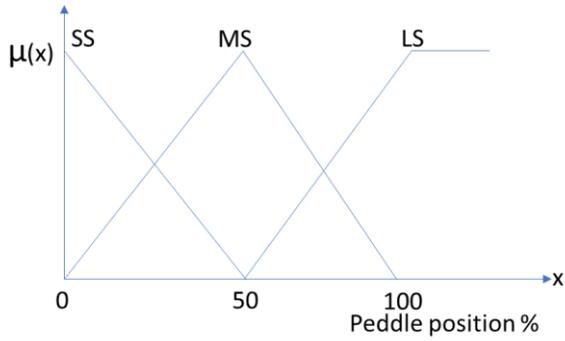
Define range of Brake Pedal Position, Membership Function of the input and output variables. We use Triangular Membership Functions.

Range for Brake position (0 to 100):

SS: 0 to 50

MS: 0 to 100

LS: 50 to 100



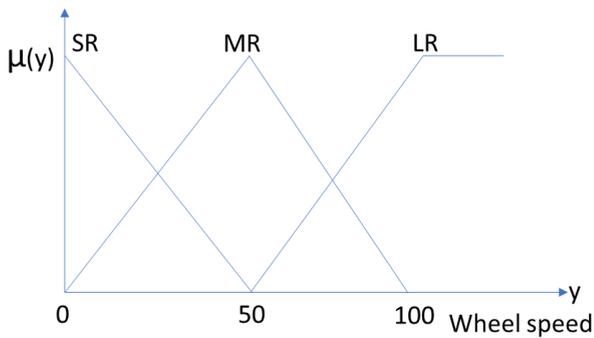
Define range of wheel speed, Membership Function of the input and output variables. We use Triangular Membership Functions.

Range for wheel speed (0 to 100):

SR: 0 to 50

MR: 0 to 100

LR: 50 to 100



Membership function for Regenerative Voltage:

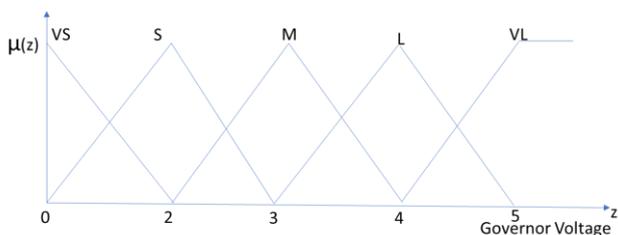
VS: 0 to 2

S: 0 to 3

M: 2 to 4

L: 3 to 5

VL: 4 to 5



$$\mu_{VS}(z) = 2 - z/2 - 0$$

$$\mu_S(z) = z - 0/2 - 0, \quad \mu_S(z) = 3 - z/3 - 2$$

$$\mu_M(z) = z - 2/3 - 2, \quad \mu_M(z) = 4 - z/4 - 3$$

$$\mu_L(z) = z - 3/4 - 3, \quad \mu_L(z) = 5 - z/5 - 4$$

$$\mu_{VL}(z) = z - 4/5 - 4$$

**RULE BASE FOR GOVERNER VOLTAGE:**

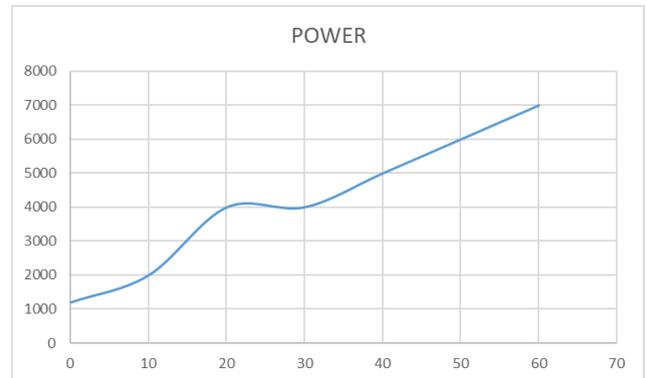
PEDAL \ SPEED	SR	MR	LR
	SS	VS	S
MS	S	M	L
LS	M	L	VL

**VII. PERFORMANCE CHARECTERISTICS**

Performance of the system tested in three steps to give a clear picture of contribution of regenerative braking. The three steps are:

1. Engine Power delivered to the wheels during acceleration.
2. Engine Power Consumed during deceleration
3. Regenerative Braking Power generated from wheels

Fig.3 indicates a graph in performance of engine delivering power to the wheels.

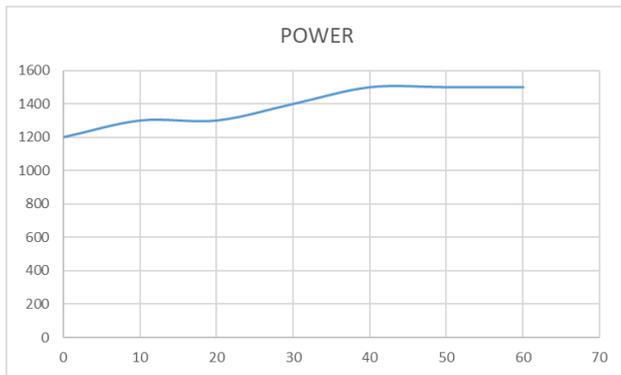


**Fig.3 Engine Power delivered to wheels during acceleration**

This power is mechanical power in terms of RPM and Torque. This is picked up from OBD of the vehicle. Readings are taken from 0 – 60Km/H. As speed increases the power developed by the

engine increases. This is called terrine power need of the vehicle. This power is directly reflecting to the consumption of fuel. Can be observed that Power developed during 0Km/H is somewhere around 1200W when converted to electrical parameter. This 1200W is survival power.

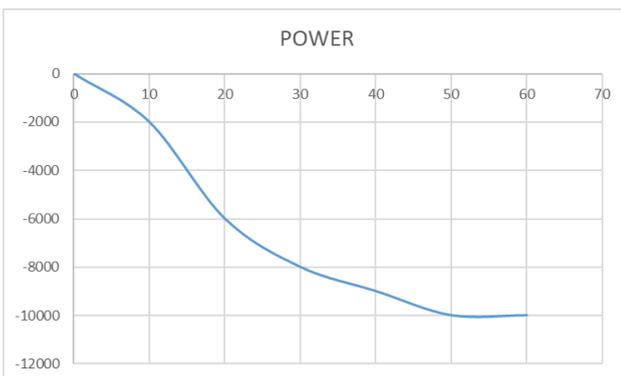
Fig.4 indicates a graph in performance of engine releasing energy for its own survival at different speeds.



**Fig.4 Engine Power Consumed during deceleration**

At a speed of 60Km/H the engine releases 1500W energy. This is called engine retarding function in Internal Combustion Engine. Energy dispense for retarding function and survival corrupts efficiency of engine. In turn this reflects in fuel consumption.

Fig.5 Indicates Regenerative Braking Power generation from the wheels. During fuel run or Electric run this performs to power pulse charge the battery bank (Rufer and Barrade, 2001) (Dixon, 2010).



**Fig.5 Regenerative Braking Power generated from wheels**

The graph indicates that power generated during braking is a maximum of 10000W at 60Km/H speed and as the speed rolls down the power generated falls. This is indicated as negative power since it is a power draw from the wheels with respect to power delivered to wheels in earlier cases. Regenerative braking power is higher than the power delivered by

the engine. Power stored in the battery bank is used while take off, assist during labouring, gear shifts and at acute power demands at the wheels (Gao, et. al., 1999).

## VIII. CONCLUSION

This approach is most recommended in both Diesel engine vehicles and petrol engine vehicles. This continuously monitors and tracks the performance of the engine driven wheels to run efficiently. The power delivery to the wheels is regulated and shared by the engine and electric motor. When it comes to the performance of automobile this system gives a smooth pull, fast take off and counters unnecessary burning of fuel. Kinetic energy is converted to electrical power and stored in the battery. This results out with the weight of the vehicle and payload while braking. Mechanical friction brakes are applied during emergency condition only.

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