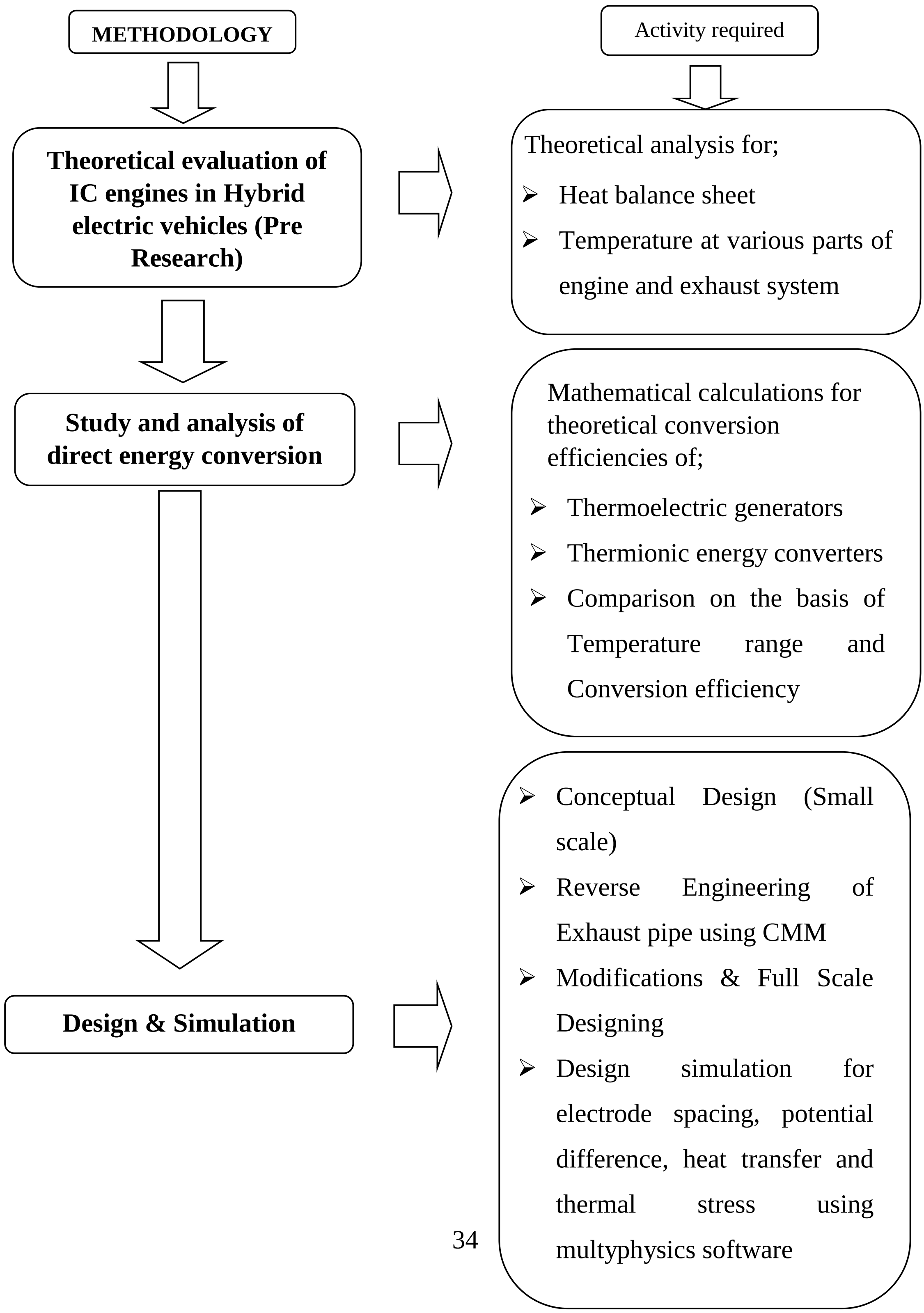
CHAPTER 3

RESEARCH METHODOLOGY

The research methodology considered for this study is categorized as design, simulation, experimentation and results validation. A details step by step methods along with the activity are mentioned in the flow chart as shown in Fig.3.1. It includes preliminary data collection for calculation of available heat sources.



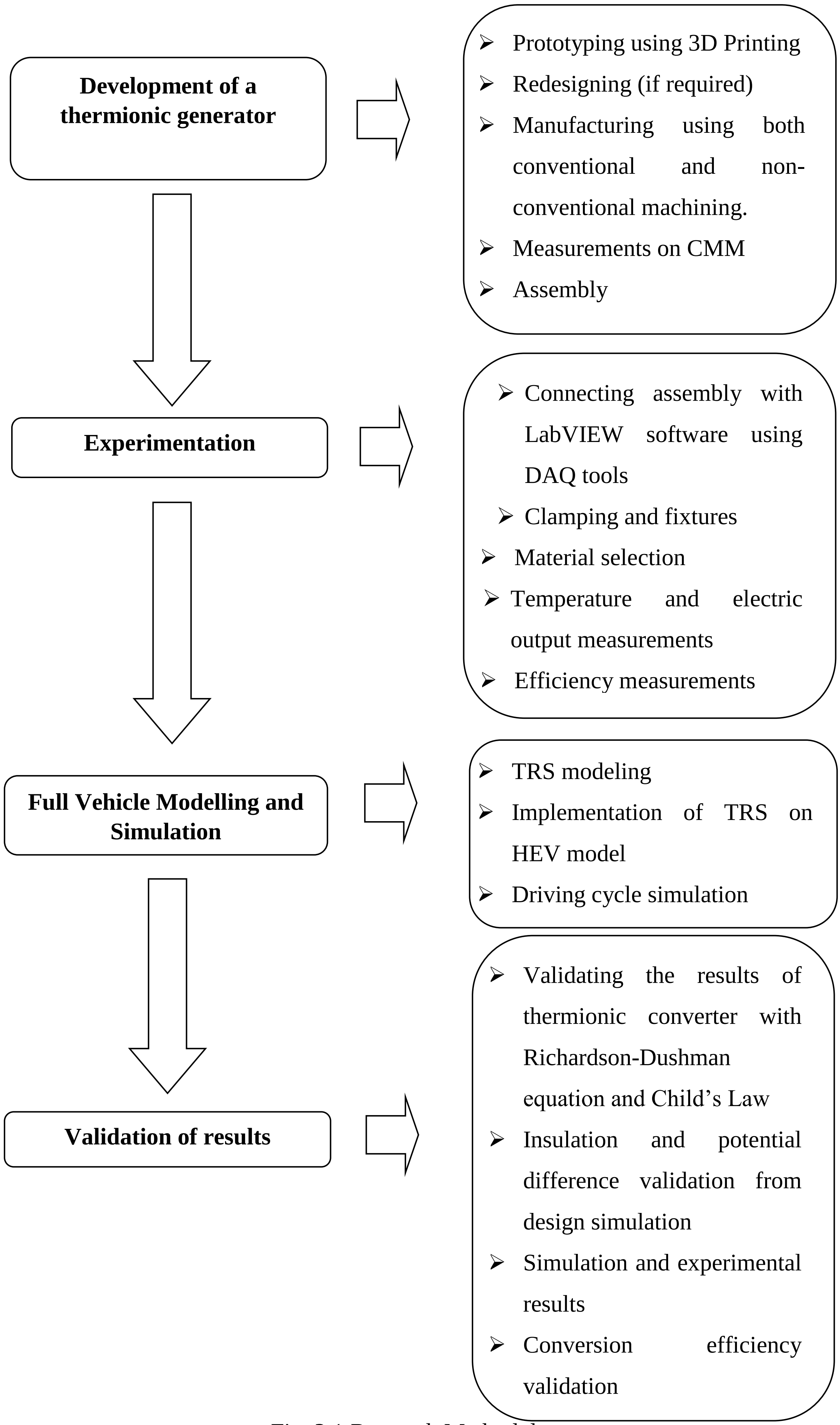


Fig. 3.1 Research Methodology

3.1 Pre- Research data collection and Calculations

A pre-research data collection and calculations are done to check the feasibility of the concept of waste heat to electricity conversion. This study is significant to identify the available energy in automotive vehicles for regeneration/ reutilization. This section includes two categories of the pre-research study necessary for formulating further calculations and analysis. These two categories are;

1) Theoretical calculations for heat lost from existing hybrid electric vehicles.
2) Measurement for maximum exhaust gas temperature from a vehicle.

3.1.1 Theoretical calculations for heat lost from existing hybrid electric vehicles.

In theory, a Heat Balance Sheet is used to calculate the heat analysis of an internal combustion engine. A heat balance sheet is a report that shows how much heat was supplied and how much heat was wasted in other systems. Table 3.1 lists the formulae that can be used to calculate the heat balance sheet of hybrid electric cars.

Table 3.1. Heat Balance Sheet Equations

● Total Heat supplied Heat supplied = $m_f \times C$ KJ/min Where, m_f is mass of fuel per minute C is calorific value of fuel	● Heat equivalent to break power When power is given in KW P_b = KW × 60 KJ/min
● Heat carried away by water Heat to cooling water= $m_w\ c_{pw}\ (t_2\text{-}t_1)$ Where m_w is mass of water c_{pw} is specific heat of water t_2 outlet temperature t_1 inlet temperature	● Heat carried away by exhaust Heat to exhaust= $m_g\ c_{pg}\ (t_{2g}\text{-}t_{1g})$ Where m_g is mass of air flow c_{pg} is specific heat of gas/air t_{2g} is outlet temperature of gas t_{1g} is intake air temperature

As this study is conducted to identify the heat loss in different hybrid vehicles. This is based on the data available for different OEMs and theoretical calculations were done to establish a range of heat loss available for conversion into useful form. A theoretical calculation for heat loss in existing hybrid vehicles is done using fuel consumption statistics from vehicle mileage data. The Table 3.2 shows, waste heat lost from existing hybrid electric vehicles. This waste heat is a potential energy source for regeneration & reutilization for improving vehicle's overall performance.

Table 3.2. Heat Balance Sheet Calculations

Hybrid Electric Vehicle	**Engine (cc)***	**Fuel Consumption (Km/l) ***	**Fuel Consumption (kg/min)* approx.**	**Engine Output (Kw)***	**Net Hybrid Power Output (Kw)***	**Heat Supplied (Kw)**	**Heat and Friction losses (Kw)**	**Heat Lost %**
Toyota Prius	1800	24	0.3	71	90	236.5	165.5	**70**
Toyota camry	2500	19	0.4	131	155	315.3	184.3	**58**
Honda Civic	1500	22	0.27	70	82	212.8	142.8	**67**
Honda Accord	2000	23	0.35	114	158	275.9	161.9	**59**
Maruti Ciaz	1400	24	0.26	66	66	204.9	138.9	**68**
Maruti Ertiga	1300	25	0.23	66	66	181.3	115.3	**64**

*Data collected from official websites of respective OEM

The Table 3.2 shows existing HEVs and their performance parameters like engine capacity, fuel consumption, engine power output and heat supplied. It is found from the calculations that an average 60% loss is from heat. Although this is a theoretical calculation, there is a significant potential in waste heat for reutilization. Along with this study, live data of exhaust gas temperature is collected to identify the maximum temperature in exhaust.

3.1.2 Measurement for maximum exhaust gas temperature from a vehicle.

Internal Combustion engine heat is lost from cooling and exhaust system majorly. Total heat supplied to IC engine is theoretically calculated using rate of fuel consumption. The data of engine's fuel consumption and temperature of exhaust and cooling system is taken using BOSCH On board Engine Diagnosis Setup (KTS 590) at School of Automotive Skills as shown in Fig.3.2 & Fig. 3.3.

Fig. 3.2. Setup showing connection of BOSCH KTS 590 with vehicle OBD

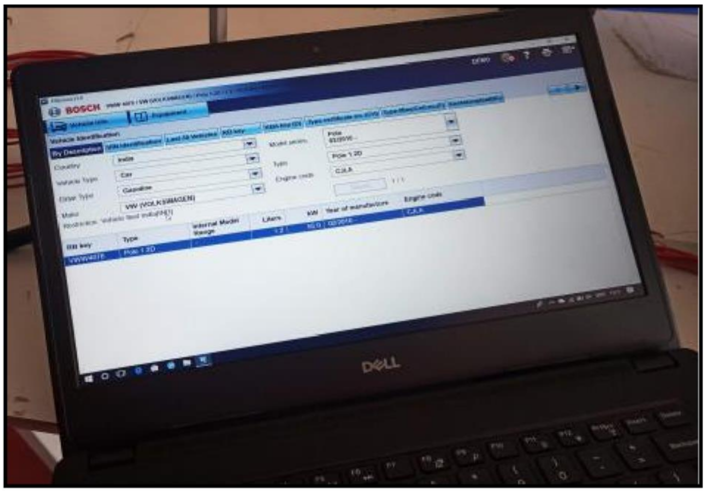


Fig. 3.3 Desktop Window for showing ESI (tronic) dashboard

Vehicle: Volkswagen Polo

Engine Specification:

- Capacity and Fuel Type: 1.2lit, Petrol
- Max Power: 103 bhp @ 5000 RPM
- Max Torque: 175 Nm @ 1500 RPM

Data Collection

To perform design simulation, it is necessary to collect reference data from vehicle. Hence, data is collected for temperature and gas flow rate from the vehicle available at School of Automotive Skills. The engine rpm was increased gradually from idling till the exhaust temperature after catalytic convertor reached 626.7^0C.

- Temperature and Exhaust gas mass flow rate measurement (exhaust and cooling system)
- Apparatus used:

1. K type thermocouple – Temperature Sensor
2. MAX 6675 thermocouple module – To convert digital signals to temperature value
3. Arduino Uno – Data Acquisition tool
4. KTS Diagnostic tool – For Engine speed, load, mass flow rate and fuel consumption measurements.

- Data collection setup;

1) K type thermocouple was connected to exhaust system at location after catalytic converter.
2) MAX6675 thermocouple module was used to connect thermocouple with Arduino UNO.
3) PLX DAQ is used to store the data in Excel sheet.
4) Intake air flow rate, exhaust gas flow rate and fuel consumption is recorded at same speed and load using KTS engine diagnosis tool.

Test Process:

1. Considering the standards for Indian driving cycles, the total test duration of 400 sec is finalized and
2. The engine RPM is gradually increased from 0 to 4000 RPM
3. The readings of relative engine load, relative air flow rate, exhaust gas flow rate, fuel consumption, exhaust & intake temperatures are taken randomly for every 40 Sec increase.
4. Test Readings: The readings shown in Table 3.3 are obtained from the BOSCH setup

The maximum exhaust gas temperature achieved during testing was 626.7 °C as mentioned in Table 3.3. The test was conducted at stationary and no load conditions. Hence it is to be noted that with further increase in engine rpm and load, exhaust temperature increases maximum up to 800^0C. This is also evident from the literature review. (Kanazaki et al., 2003)

Table 3.3. Obtained Data from Volkswagen Polo

Sr No.	Time (Sec)	Engine Speed (rpm)	Relative Engine Load (%)	Intake air flow rate (Kg/h)	Exhaust gas flow rate (Kg/h)	Fuel Consumption l/h	T1 (^{0}C)	T2 (^{0}C)
1	40	796	17.98	5.4	6.3	0.54	437.33	98
2	80	1140	12.12	5.4	5.5	0.40	428.48	99
3	120	1224	12.52	6.1	6.5	0.51	434.97	98
4	160	1288	12.52	6.3	6.8	0.50	435.83	98
5	200	1324	11.88	6.2	6.1	0.45	432.76	98
6	240	1365	12.3	6.5	7.2	0.5	437.6	99
7	280	1433	14.8	9.5	9.4	0.6	446.0	99
8	320	2397	12.3	11.7	12.3	1.0	515.6	101
9	360	2470	12.4	12	12.5	1.0	520.6	101
10	400	3510	13.2	17.9	18.8	1.6	626.7	101

Here,

T1= Temperature of exhaust after catalytic converter,

T2= Engine coolant temperature

The equations for heat supplied and heat lost (i.e. Heat Balance Sheet) are utilized to calculate the heat lost from a hybrid electric vehicle. The heat calculations done for HEVs in this pre-research study shows the amount of heat lost to the environment. This calculation hence helps to identify the potential of waste heat for recovery.

Another study by measurement for maximum exhaust gas temperature from a vehicle have shown that, the parameters of heat lost to the environment are measurable by data acquisition system. The data obtained by measurements is utilized for further study in modelling and simulation of thermionic energy conversion using mathematical expressions of Richardson Equation (i.e. for thermionic current) and Child's law (i.e. for potential difference). This methodology is hence useful for understanding the behavior of emitter materials for thermionic conversion.