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The 27th INTERNATIONAL ELECTRIC VEHICLE SYMPOSIUM & EXHIBITION
BARCELONA
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Configuration Analysis of Plug-in Hybrid Systems using Global Optimization

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Hosted by AVERE mea Ajuntament de Barcelona
In collaboration with EVAAP EDTA
Supported by European Commission

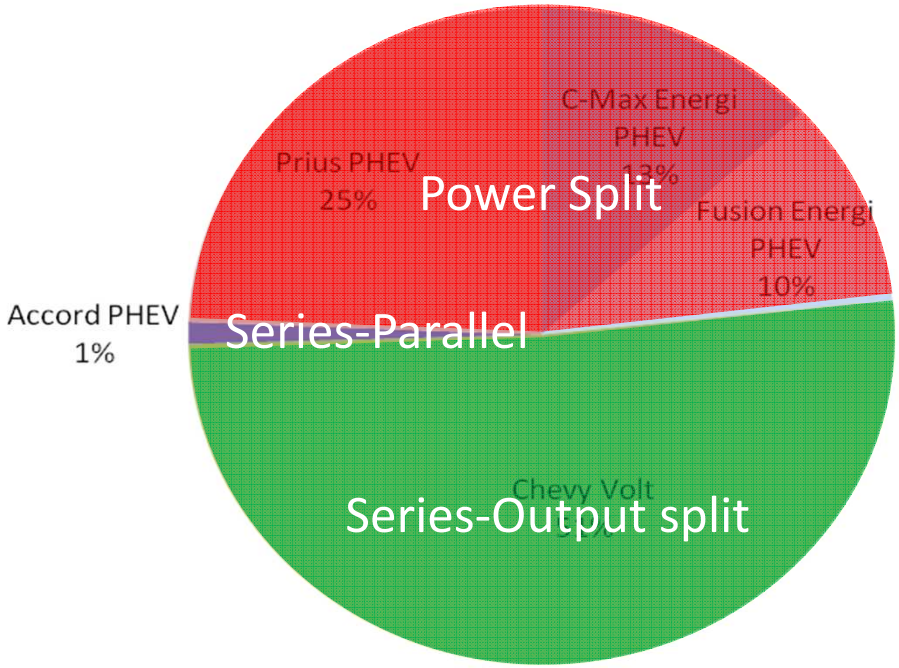
Agenda

1. **Motivation & Purpose**
2. **Plug-in Hybrid Systems**
3. **Methodology**
   - Theoretical System Analysis
   - Dynamic Programming
   - Vehicle Modeling : Transmission element loss
4. **Results**
   - Theoretical System Analysis Results
   - Dynamic Programming Results
5. **Conclusion**

1. Motivation & Purpose

- **PHEV Models**

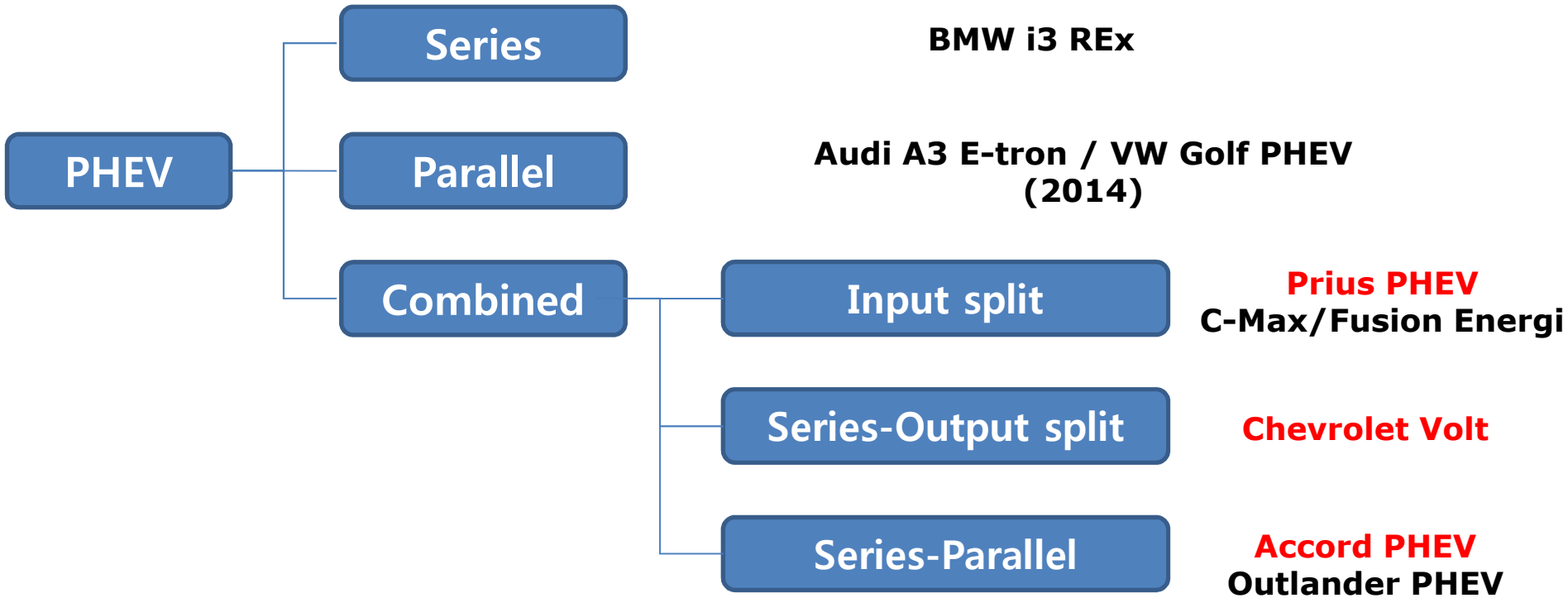
- **U.S PHEV Sales in 2013**



Which system has Benefits in certain driving conditions?

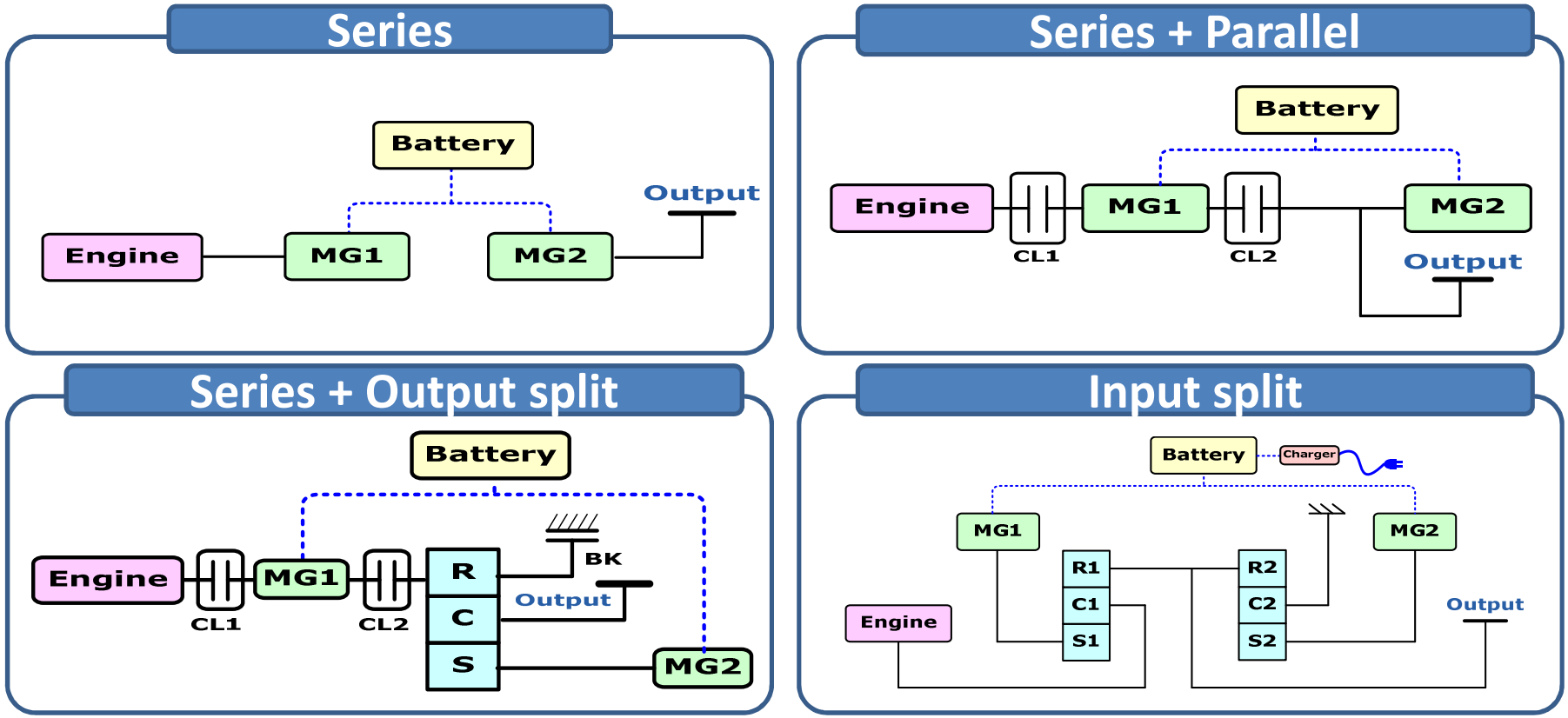
2. Plug-in Hybrid Systems

- **PHEV Powertrains Topologies (Categorized by TM Mode)**



2. Plug-in Hybrid Systems

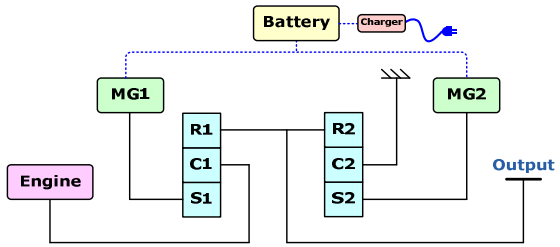
- **PHEV Powertrains Topologies**



2. Plug-in Hybrid Systems

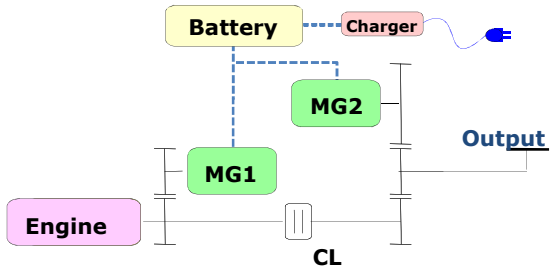
- **Configuration of (Series + α) PHEVs**

PRIUS PHEV



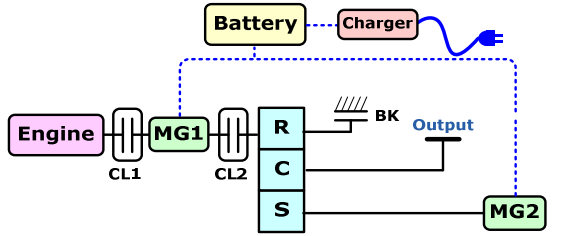
Modes	EV / Input split
BK	ON

Accord PHEV



Modes	EV / Series	Parallel
CL		ON

Volt



Modes	EV1	EV2	Series	O/S
BK	ON		ON	
CL1			ON	ON
CL2		ON		ON

the Number of TM modes ↑

=

the Number of TM Elements ↑

→ System Efficiency ↑

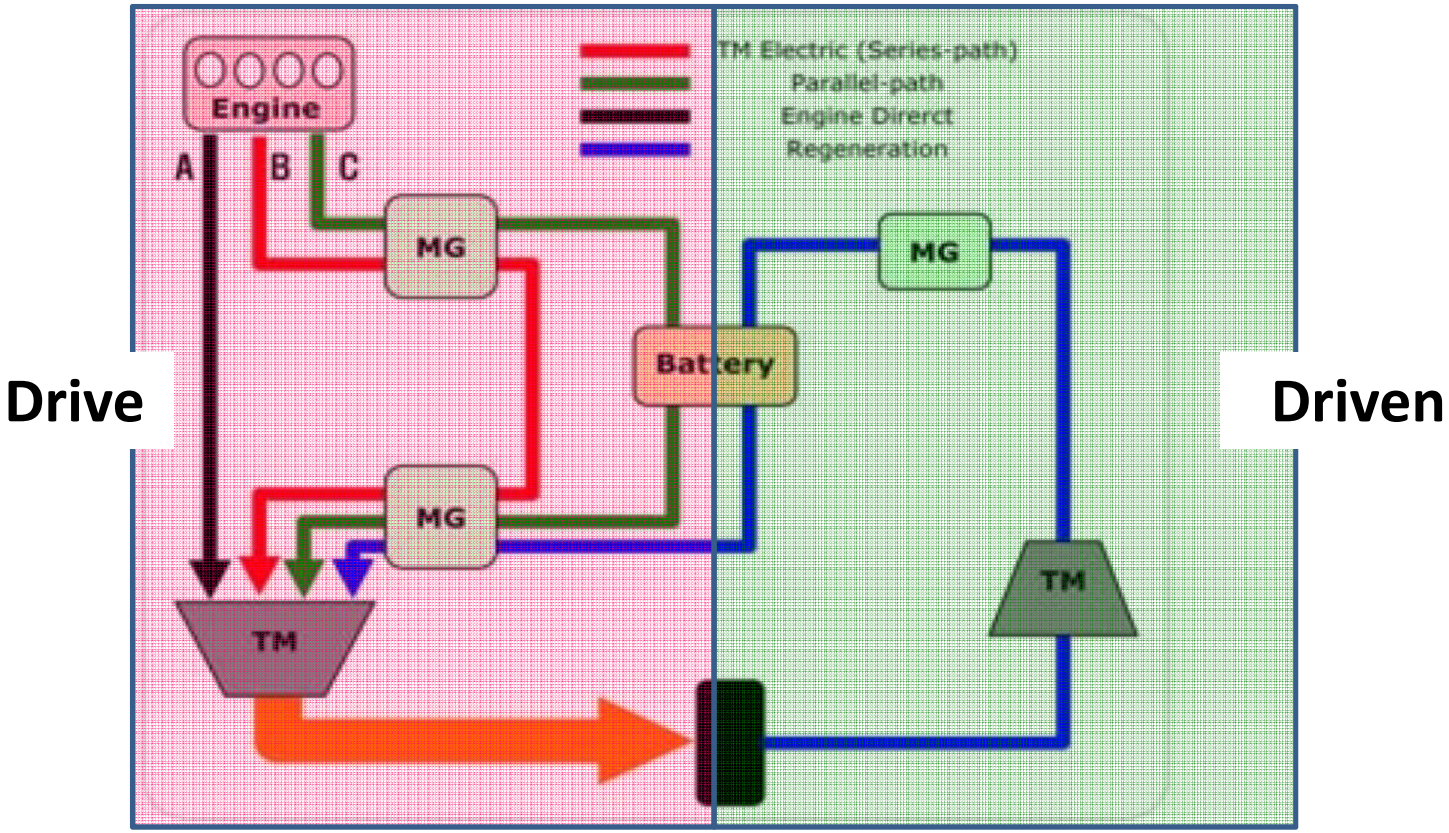
→ Complexity of Control ↑

→ Mechanical Losses ↑

The Impact of Transmission Mechanical Losses is Considered

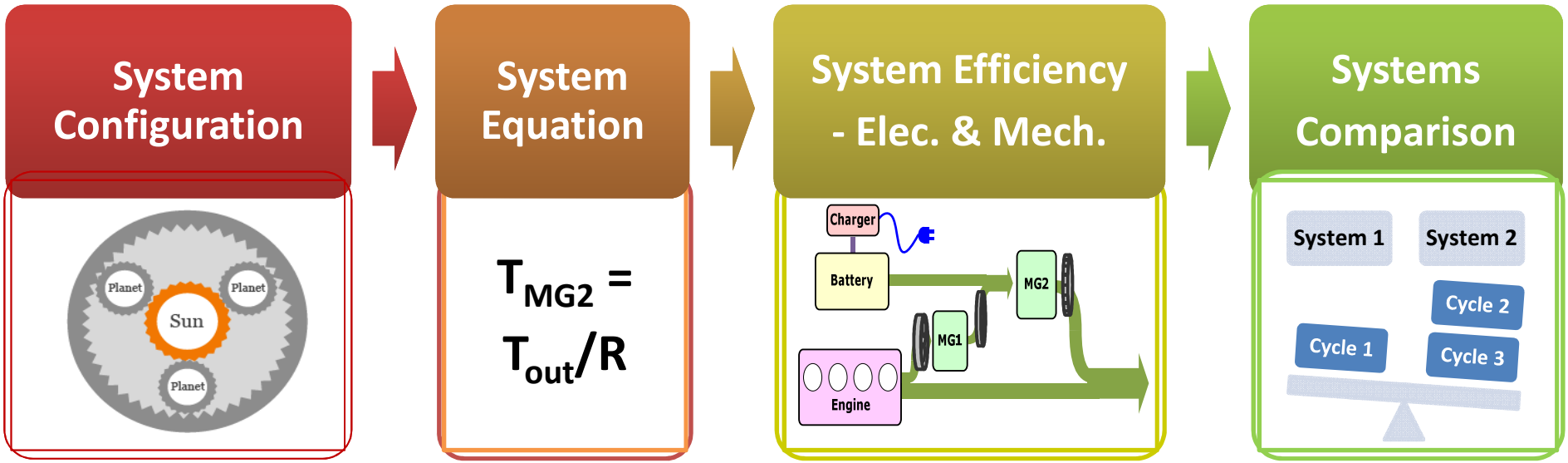
2. Plug-in Hybrid Systems

- **PHEV System Efficiency**



3. Methodology - System Analysis

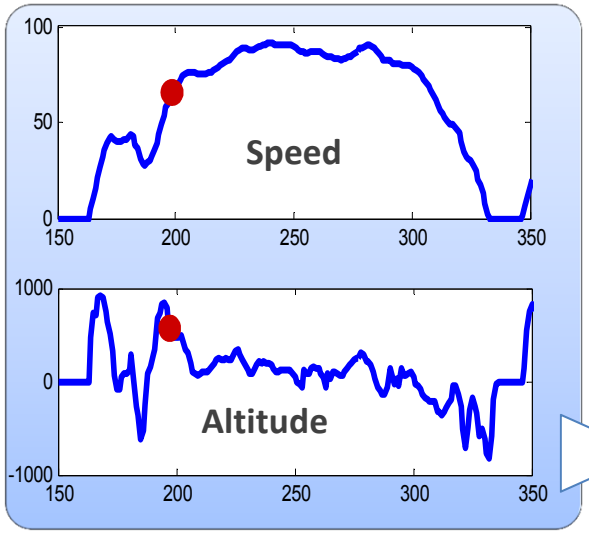
- **Theoretical System Analysis**

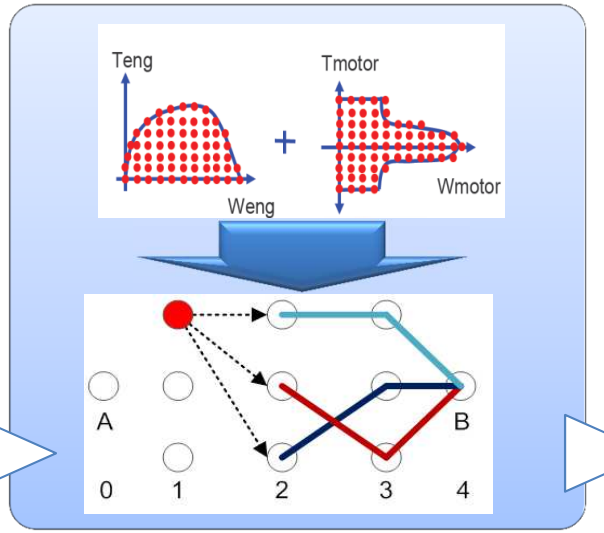


3. Methodology - Dynamic Programming

- **Dynamic Programming**

Input	Output	Object
Known Drive Cycle	Finding Optimum Operating Points	Minimizing Fuel Consumption





3. Methodology - Vehicle Modeling

- **Vehicle Specification**

Assuming Same Engine and Motor Efficiency and Final Gear ratio

Components	Input split	Series-output split	Series-parallel
Engine	1.6L Gasoline, 82kW		
MG1 / MG2	42kW / 60kW	55 kW / 111kW	100kW / 124kW
Battery	LiPB, 342V, 20Ah		
Gear Ratio	2.6 / 2.636	2.2432	0.882, 1.97, 0.575
FGR	3.5		

3. Methodology - Vehicle Modeling

- **Transmission Component Loss Modeling**

Gear
- Modeling

- Assuming Constant Gear Efficiency

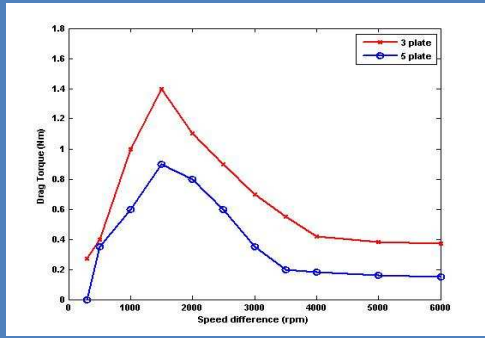
Gear Number	PG	SG
Efficiency	97%	99%
Prius	2	0
Volt	1	0
Accord	0	3

- Considering Power split ratio for PG

Clutch
-Test Data

- Test Result

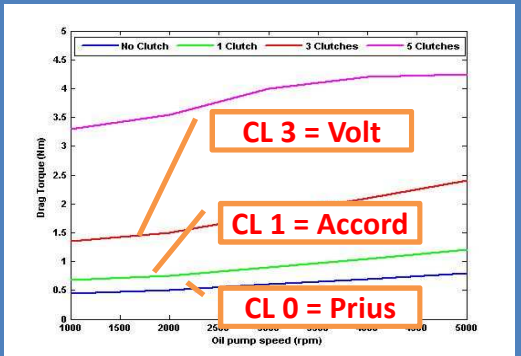
$$T_{Loss,Clutch} = f(N_{Friction}, \Delta\omega)$$



Oil Pump
- Test Data

- Test Result: Function of (Speed, Number of Clutch)

$$T_{Loss,OilPump} = f(\omega_{OilPump}, NumberofClutch)$$

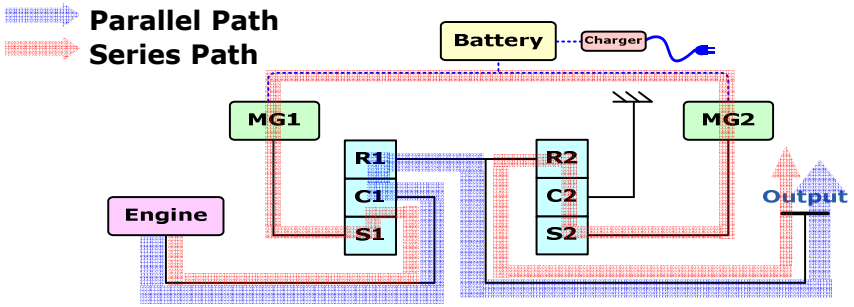


3. Methodology - Vehicle Modeling

- **Theoretical System Analysis – Gear Loss Modeling**

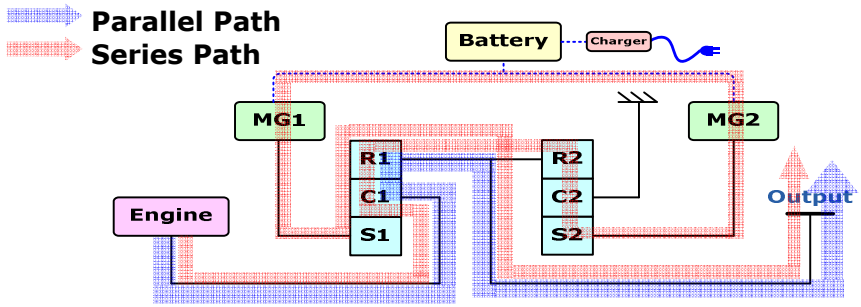
Input split

Split



- Parallel Path: Through Planetary gear 1 time
- Series Path: Through Planetary gear 2 times

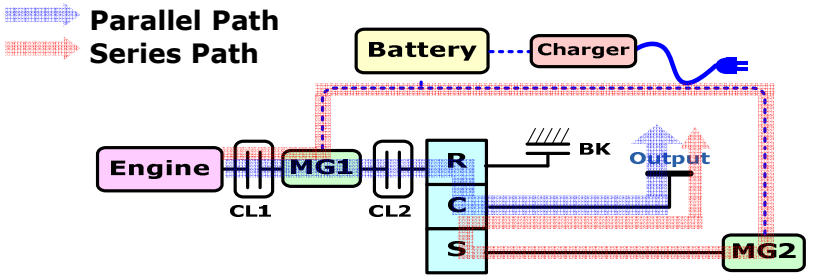
Recirculation



- Parallel Path: Through Planetary gear 1 time
- Series Path: Through Planetary gear 3 times

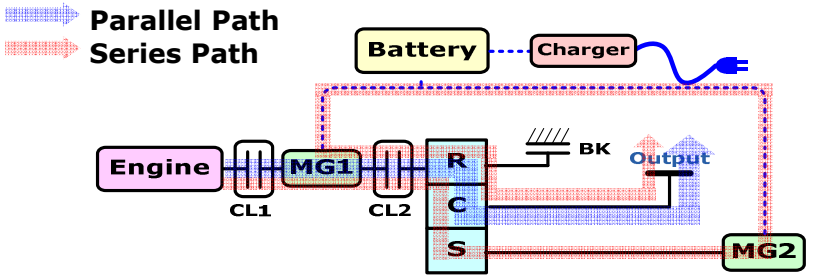
Output split

Split



- Parallel Path: Through Planetary gear 1 time
- Series Path: Through Planetary gear 1 time

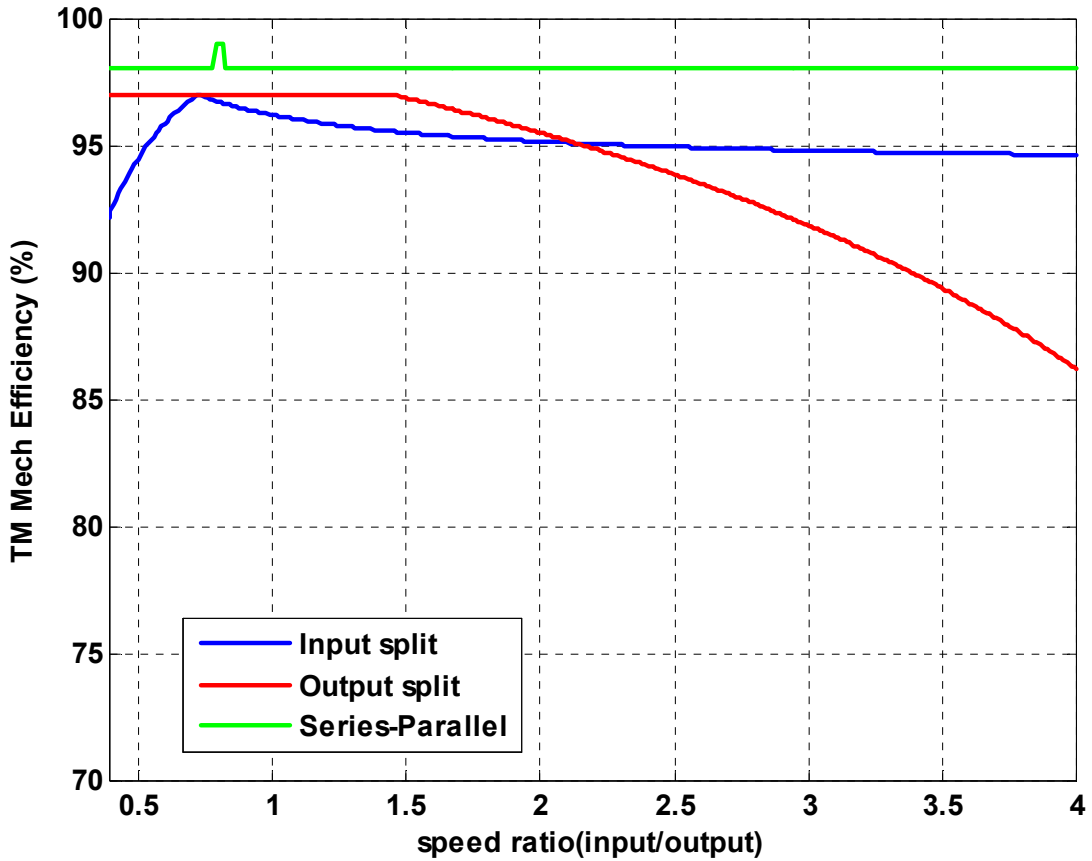
Recirculation



- Parallel Path: Through Planetary gear 1 time
- Series Path: Through Planetary gear 2 times

3. Methodology - Vehicle Modeling

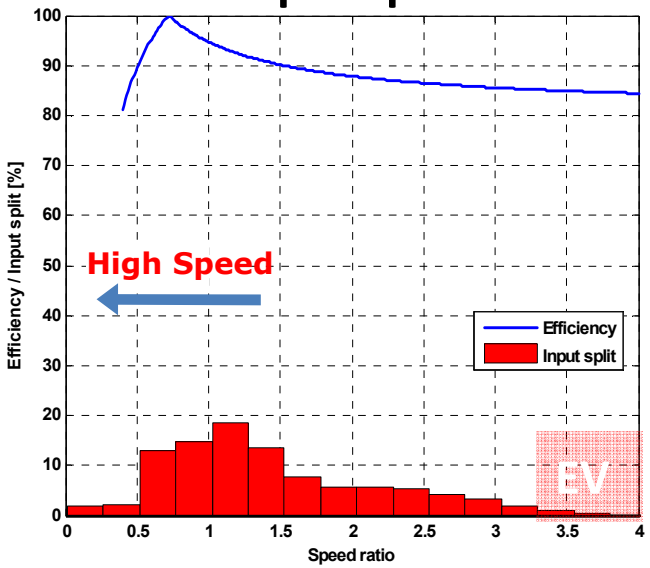
- **Theoretical System Analysis - Gear Loss**



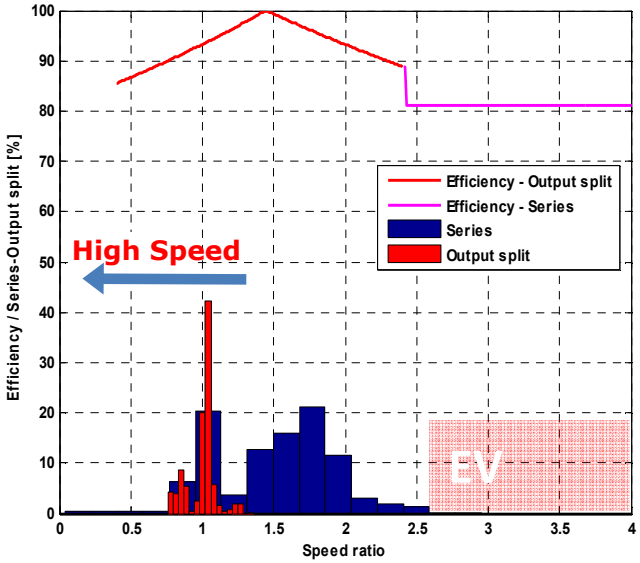
4. Result

- **Theoretical System Analysis – City Driving**

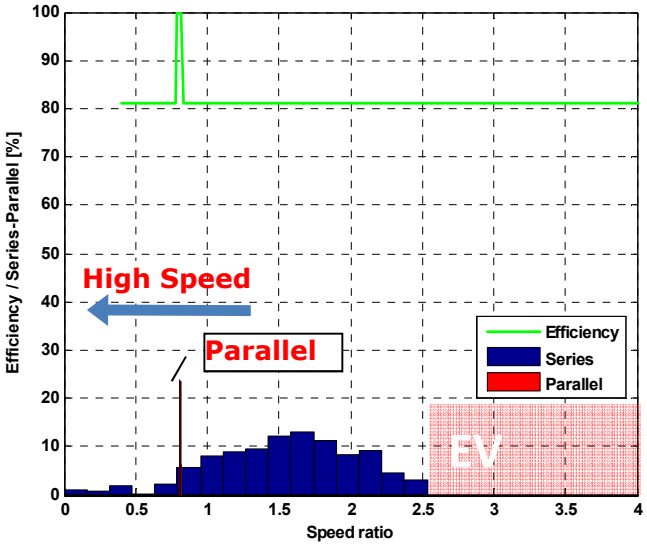
< Input split >



< Series - Output split >



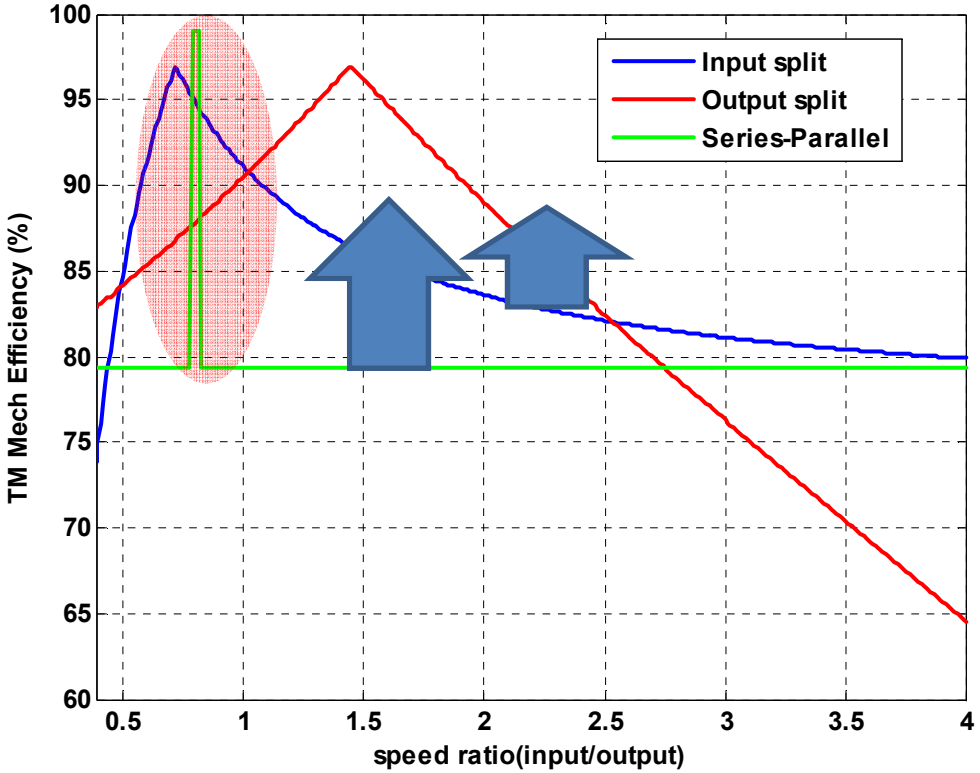
< Series - Parallel >



- **I/S :** High efficiency in **High speed ratio (City driving)**
- **S/O :** High efficiency in **Middle speed ratio (Suburban drving)**
- **S/P :** High efficiency in **Low speed ratio (Mild Highway driving)**

4. Result

- **Total System Analysis – (EM Loss × Gear Loss)**

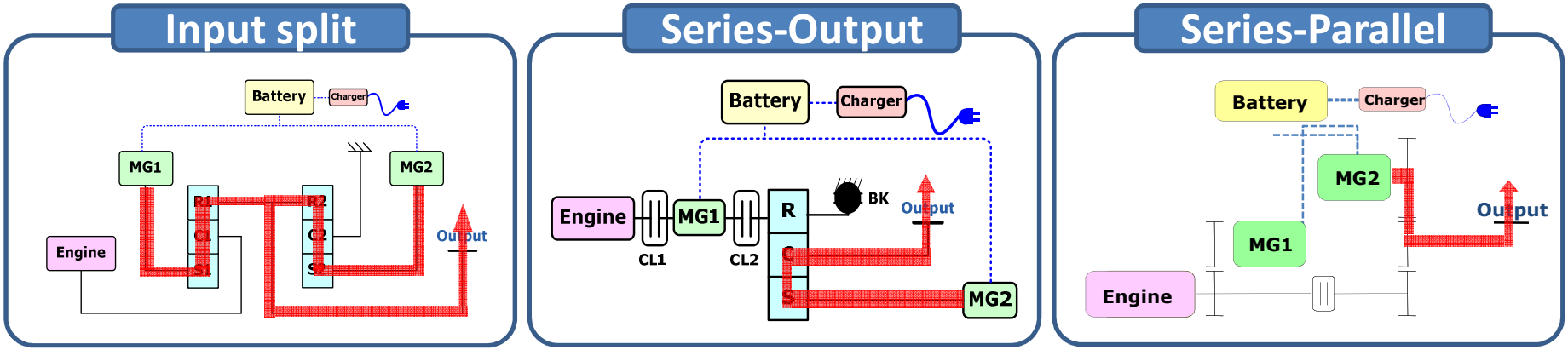


① Disadvatage fo Split Compare to Parallel

② As EM efficiency has improved, Series with Spur gear's Efficiency will improve more that Split with Planetary Gear

4. Result

- **Dynamic Programming – CD (Charging Depleting)**

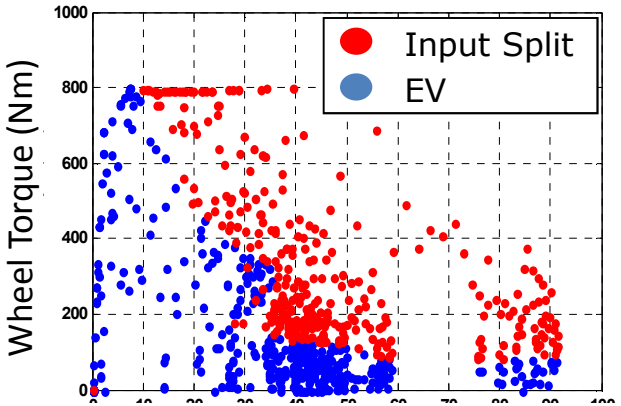


Efficiency		Input split	Series-Output	Series-Parallel
Mech. Loss	Gear Loss	97%	97%	99%
	MG drag	0~1%	0	0
Electrical Loss		90% (Assumption)		
System Eff.		**86~87%**	**87%**	**89%**

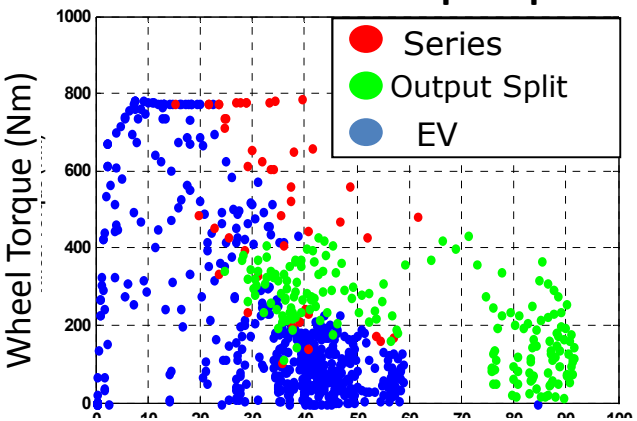
4. Result

- **Dynamic Programming – CS (Charging Sustaining)**

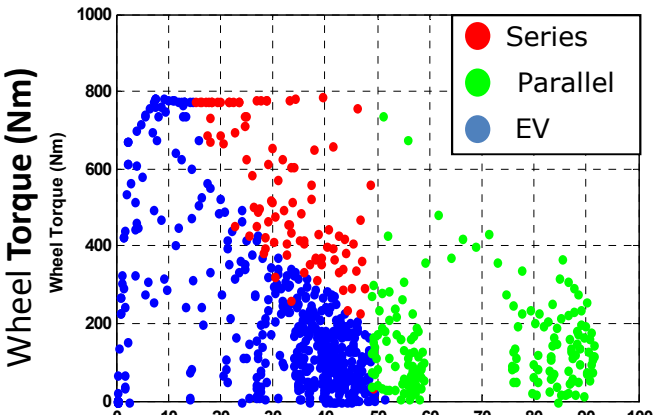
< DP result - Input split>



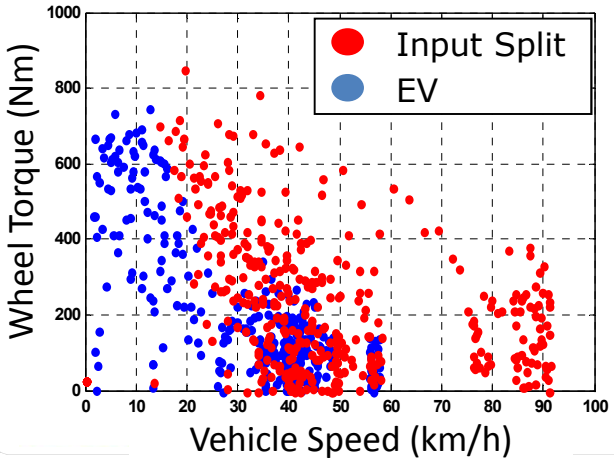
< DP result- Series Output split>



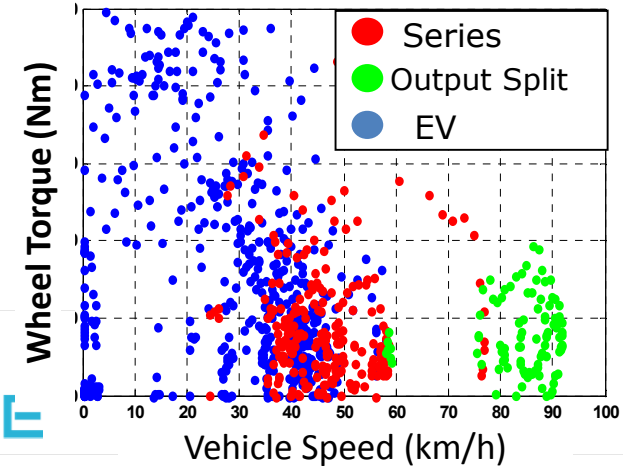
< DP result – Series Parallel>



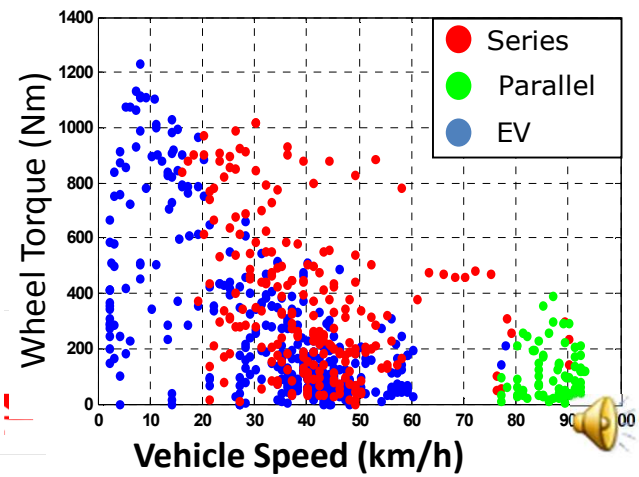
< Test result – Prius PHEV >



< Test result – Volt>



< Test result – Accord PHEV >



4. Result

Efficiency		Input split	Series-Output	Series-Parallel
CD (Mechanical)	City	96.0	96.1	96.9
	HWY	96.0	97.0	97.5
CS (System)	City	31.8	31.0	30.9
	HWY	33.2	30.1	33.4
	US06	34.1	32.2	33.9

5. Conclusion

- **PRIUS = HEV Mode – City and Aggressive Driving**
- **Volt = EV Mode and Middle speed range**
- **Accord PHEV = EV Mode + Highway**

	City	Highway	Aggressive Driving
EV Drive	Volt / Accord		
HEV Drive	Prius	Accord	Prius

5. Future Work

- **In a certain area Which driving pattern is prevalent and Which system has merits?**
- **How system type can affects the Component efficiency?**
- **Parallel PHEV's Advantage?**

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THANK YOU

Gracias

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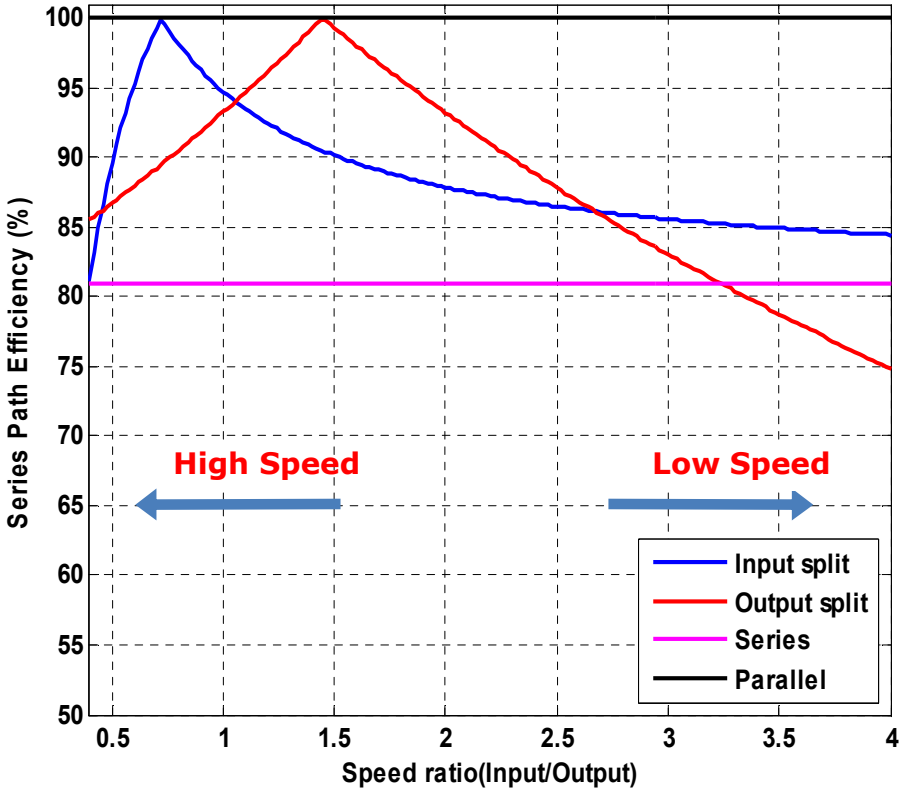
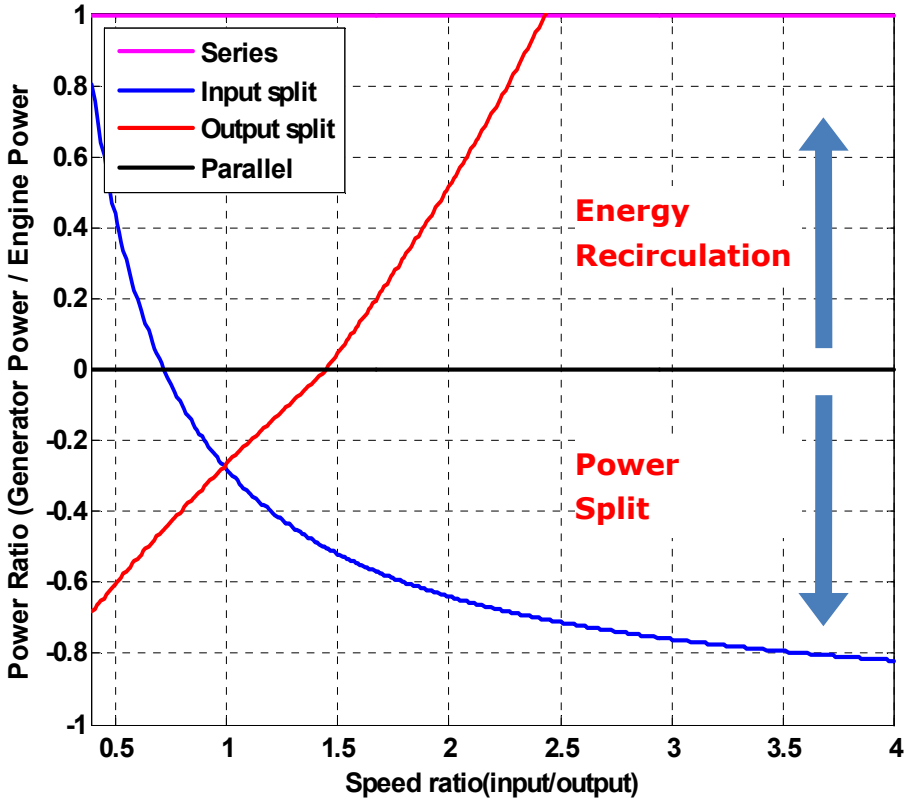
4. Result

- **Theoretical System Analysis – Series-path**





3. Methodology - Dynamic Programming

- **Dynamic Programming**

Usage of Dynamic Programming

1. Fuel Economy Potential
2. Optimum Control Strategy
3. Component Size Decision