



# Synthesis of Torque Vectoring Topologies with Hybrid Functionalities






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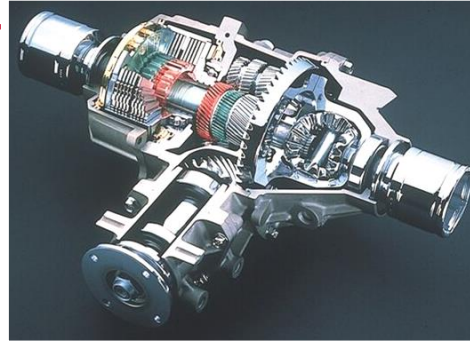
# Content

-  Overview
-  Basic Principle of Torque Vectoring with Superimposing Unit
-  PlanGear – Synthesis Program
-  Example
-  Summary

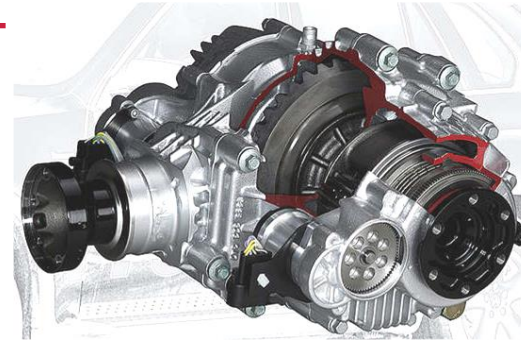


# Overview

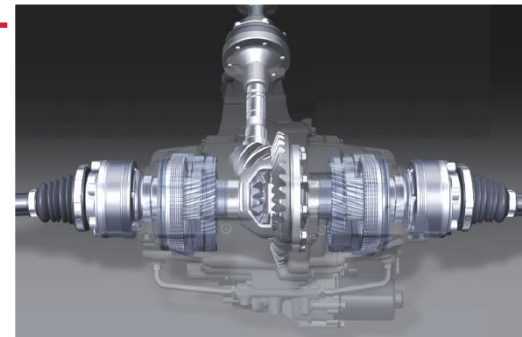
## Torque Vectoring in series production



since 1996



since 2008

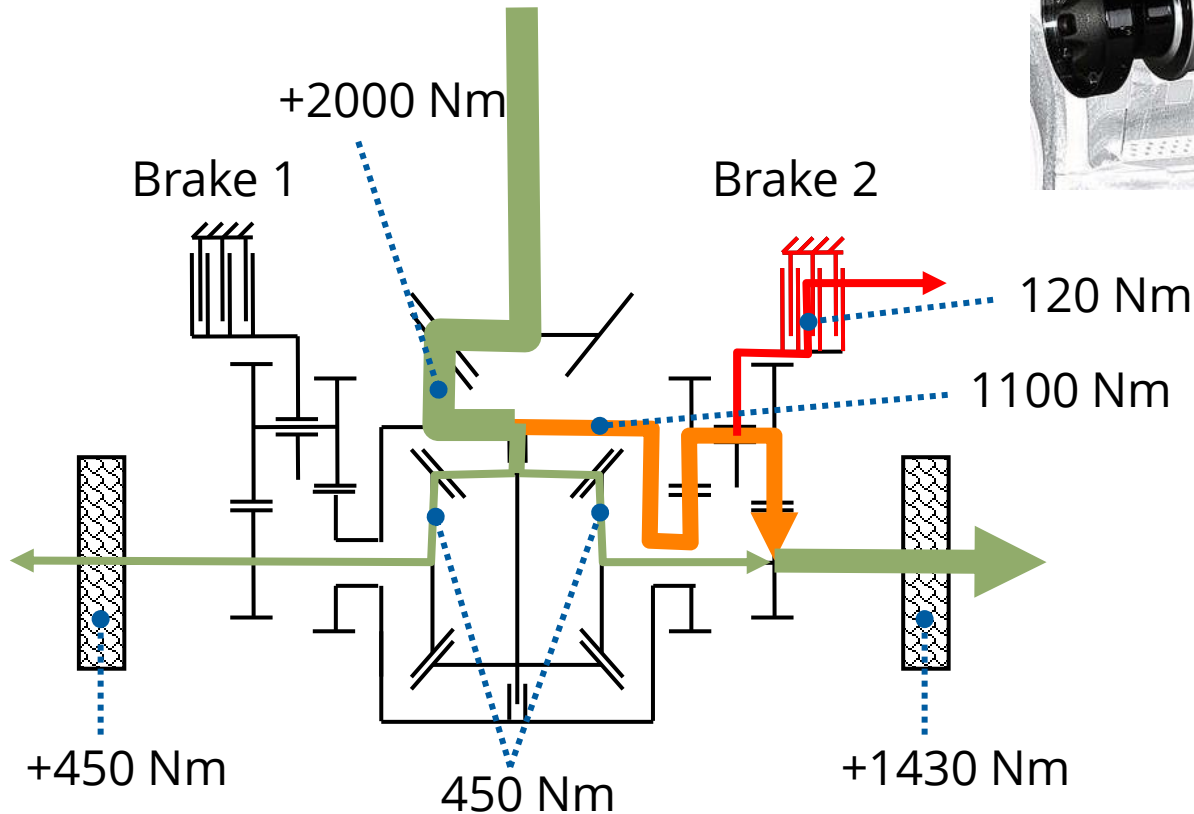
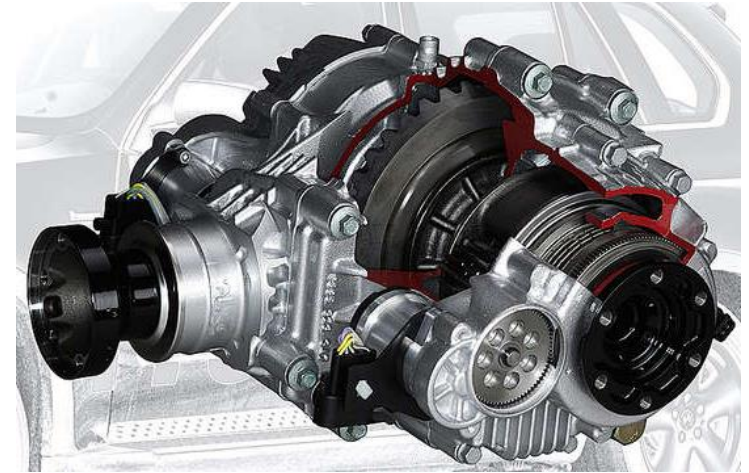


since 2008








# Overview

## Power flow - Vector Drive (BMW X6)



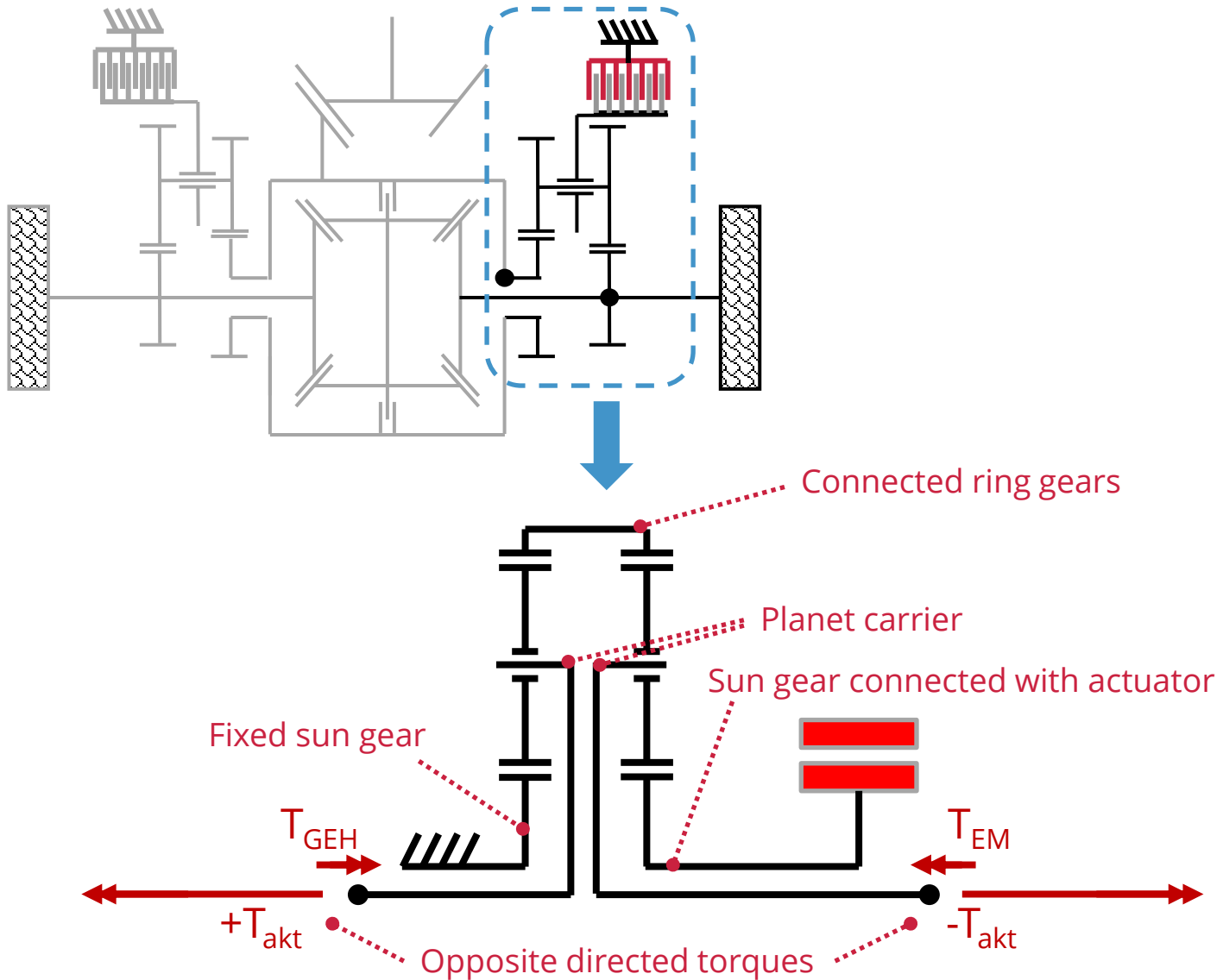


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-  Overview
-  **Basic Principle of Torque Vectoring  
with Superimposing Unit**
-  PlanGear – Synthesis Program
-  Example
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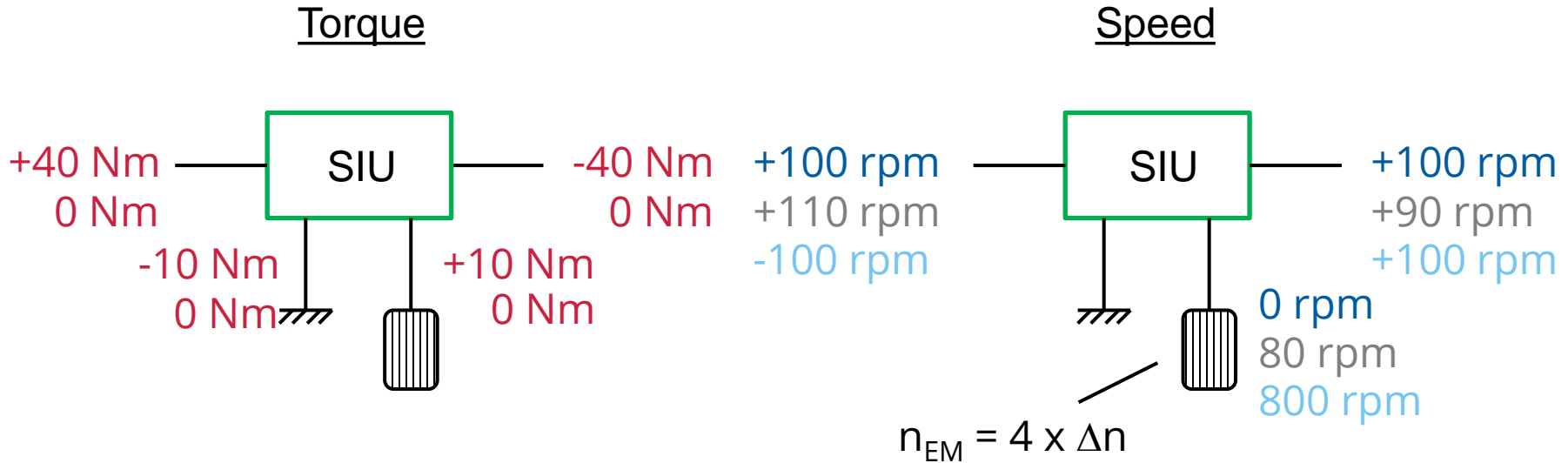
# Torque Vectoring Topologies Superimposing Unit





# Torque Vectoring Topologies

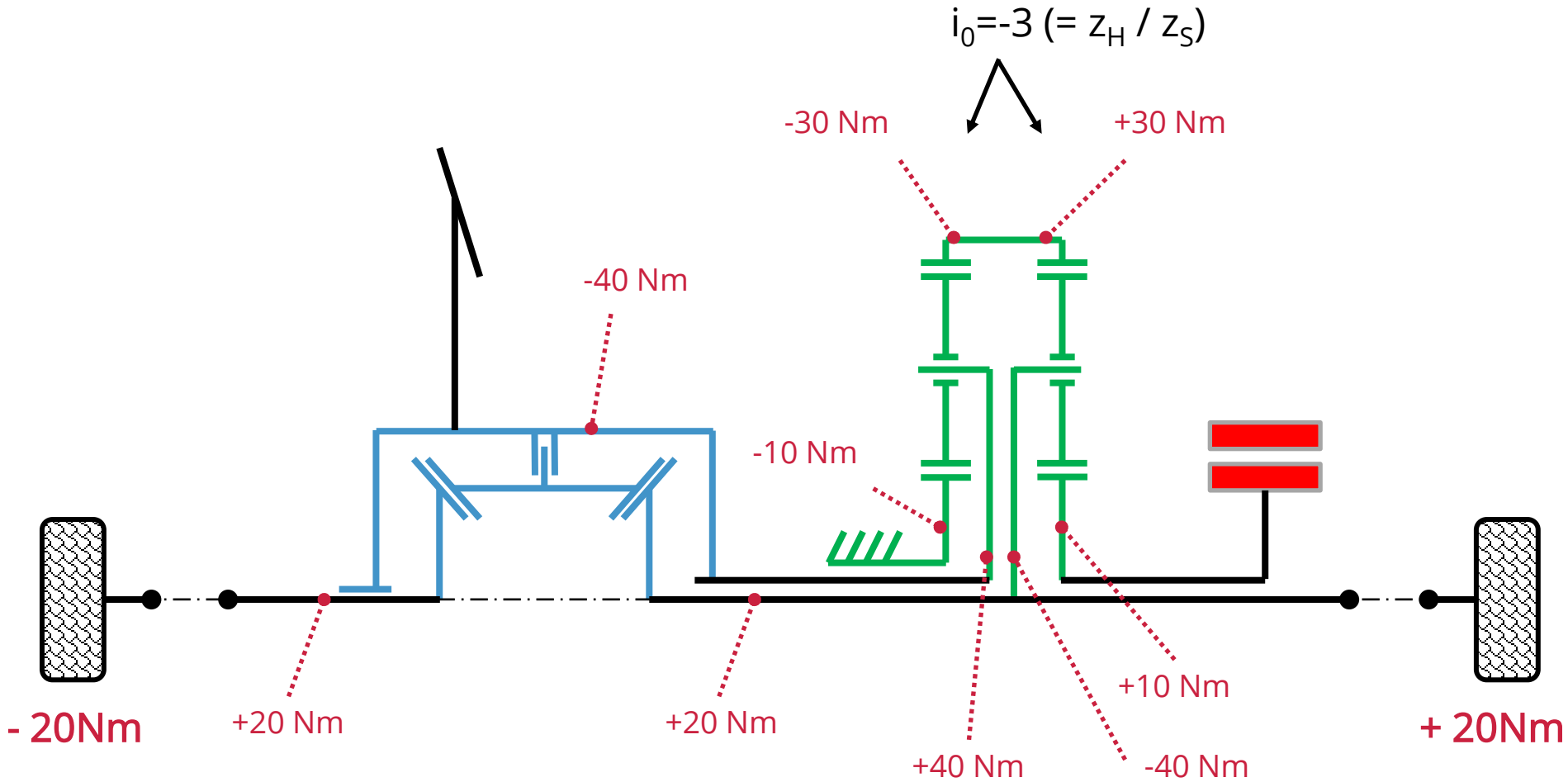
## Basic Principle - Superimposing Unit (SIU)



- Generation of torque difference independently from speeds
- Generation of opposite torques
- Ratio between torque difference between wheels to E-Motor
- Superimposing unit is state of the art (e.g. in WO 2006/029434 A3)



# Torque Vectoring Topologies Superimposing Unit



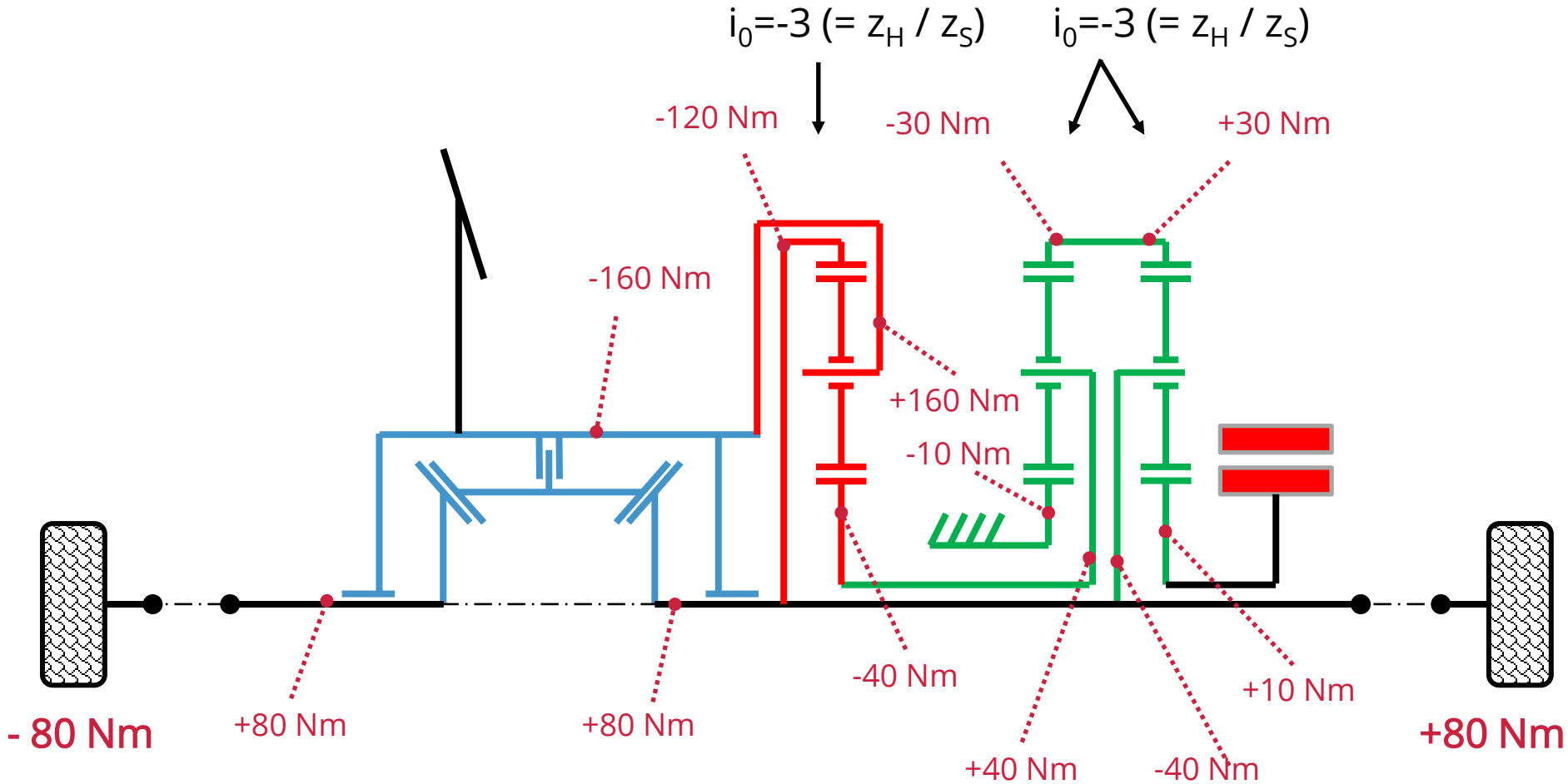
$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{20 - (-20)}{10} = 4$$





# Torque Vectoring Topologies

## Amplifying planetary gear

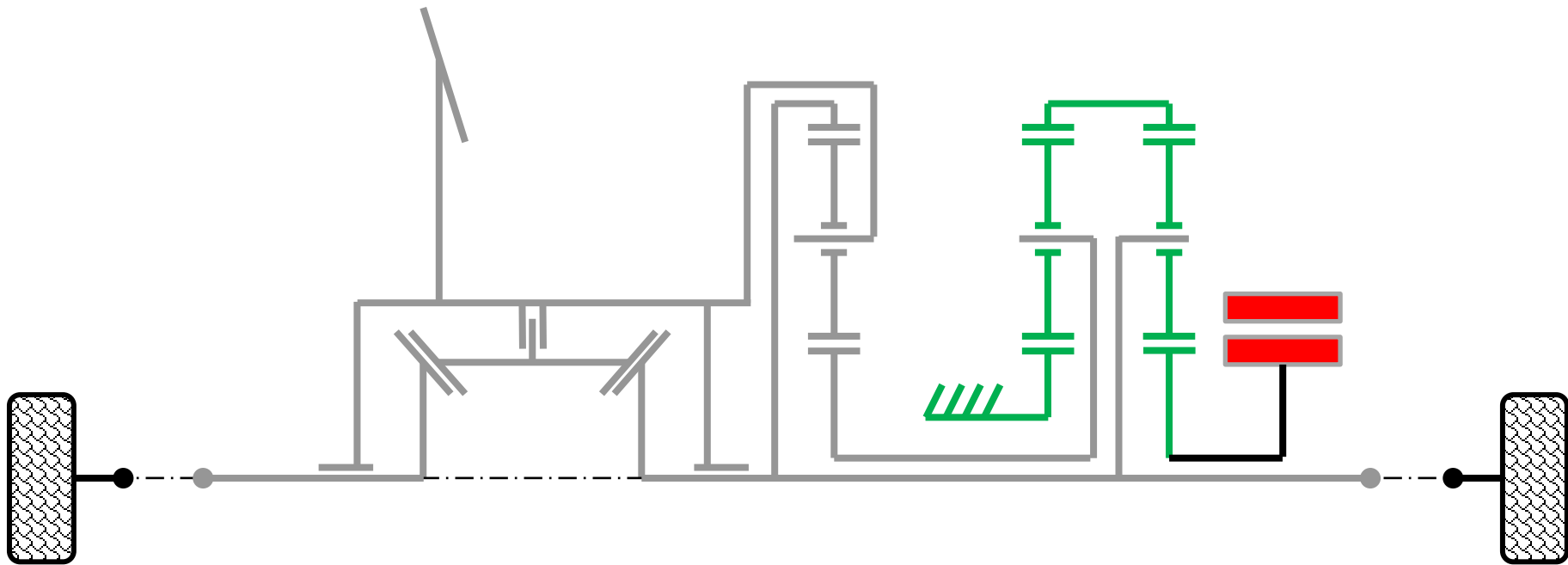


$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{80 - (-80)}{10} = 16$$



# Torque Vectoring Topologies

## Amplifying planetary gear

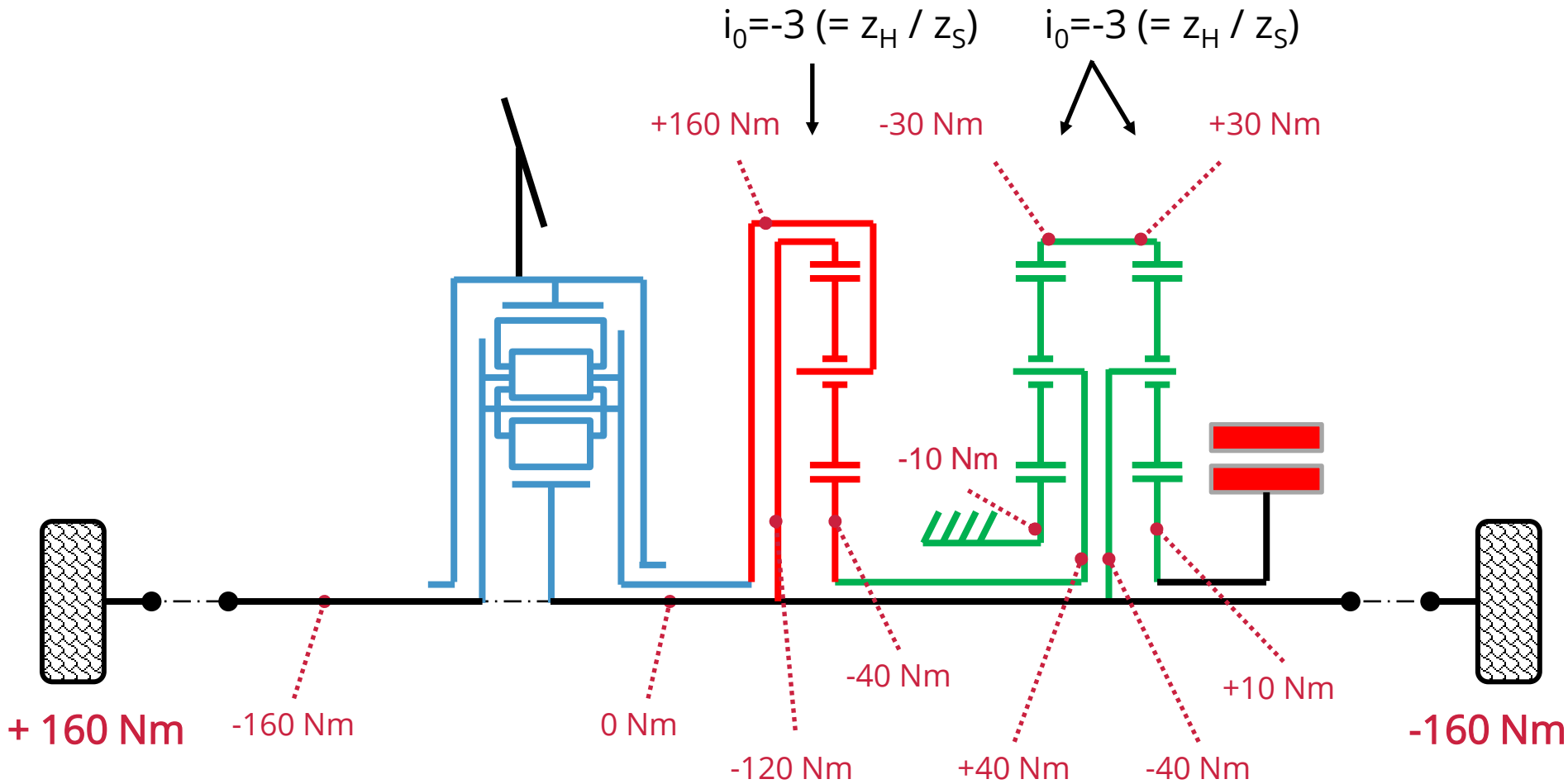


■ Shafts / gears with speed of wheels



# Torque Vectoring Topologies

## Amplifying gear + Cylindrical gear diff.

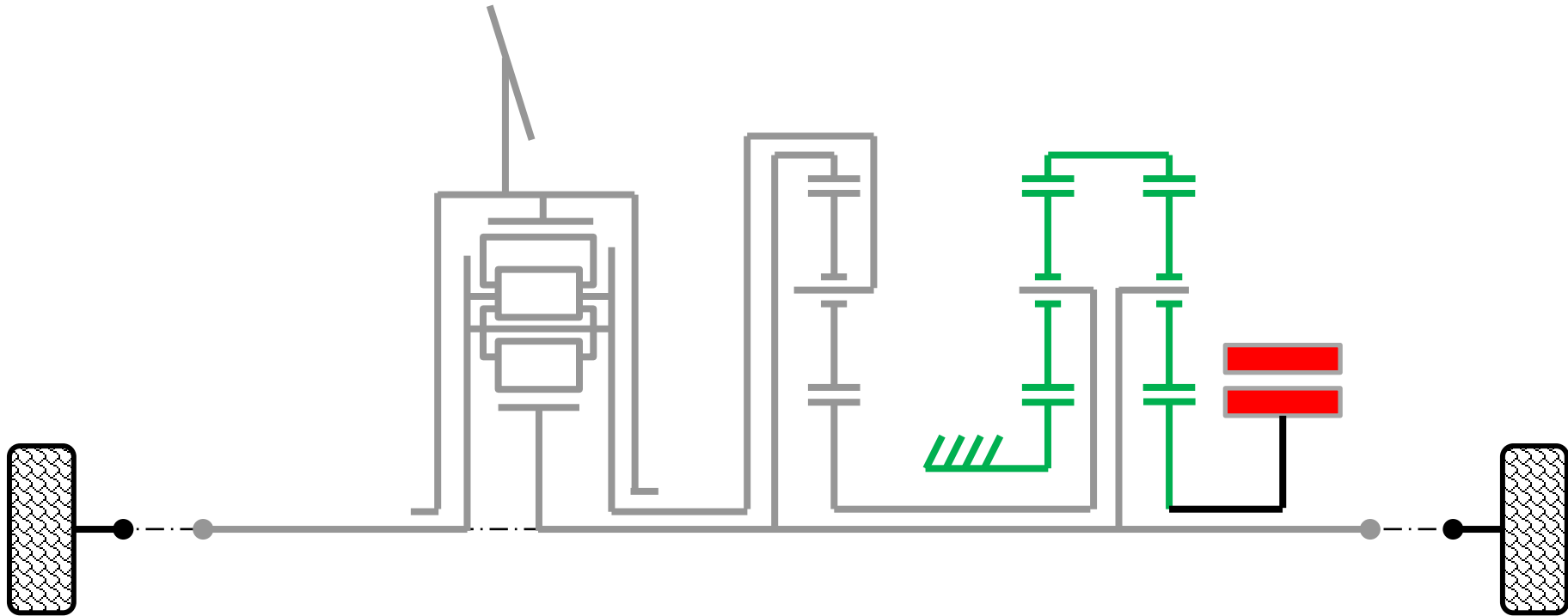


$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{160 - (-160)}{10} = 32$$



# Torque Vectoring Topologies

## Amplifying gear + Cylindrical gear diff.

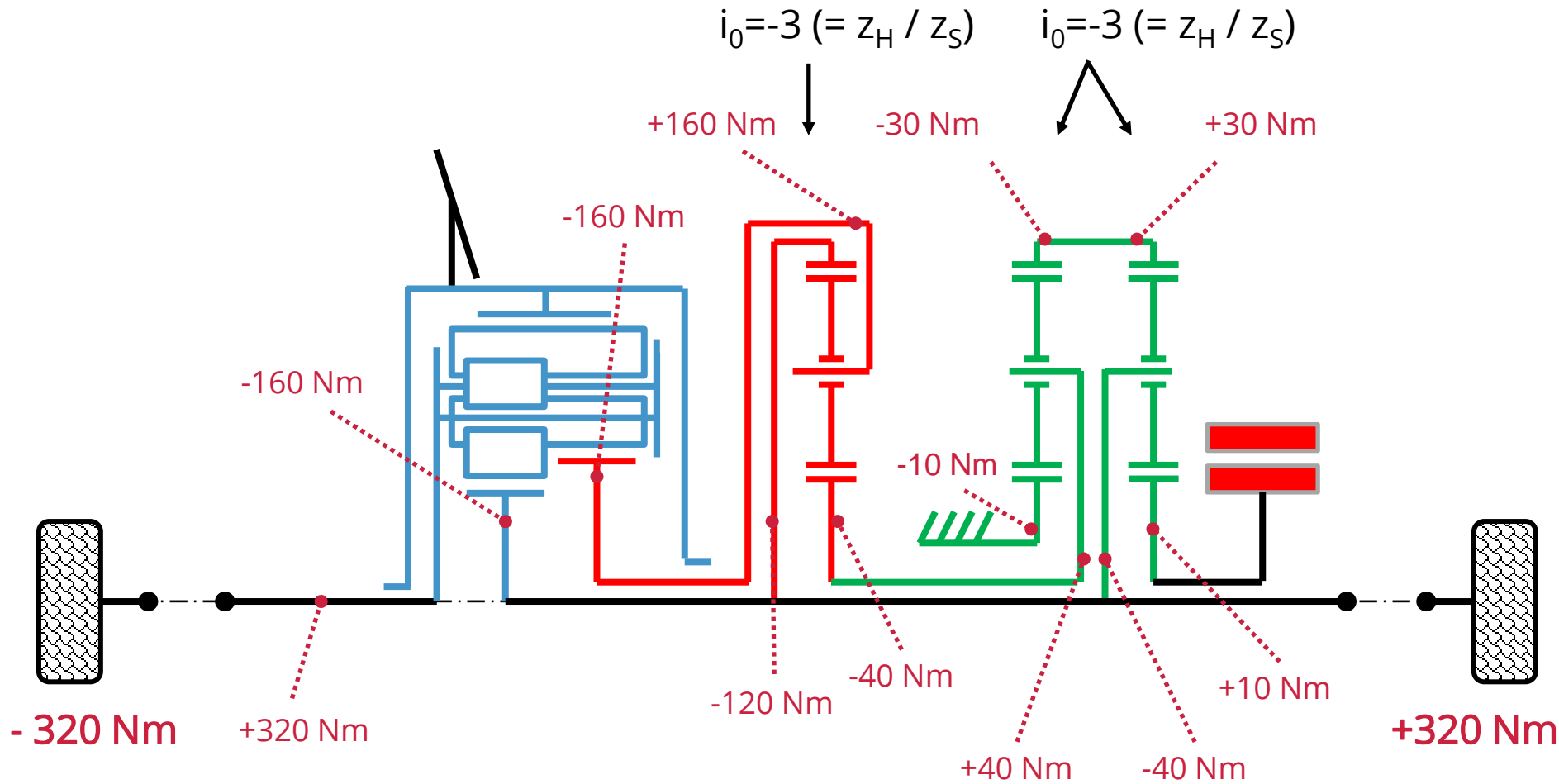


■ Shafts / gears with speed of wheels



# Torque Vectoring Topologies

## 2x Amplifying gear

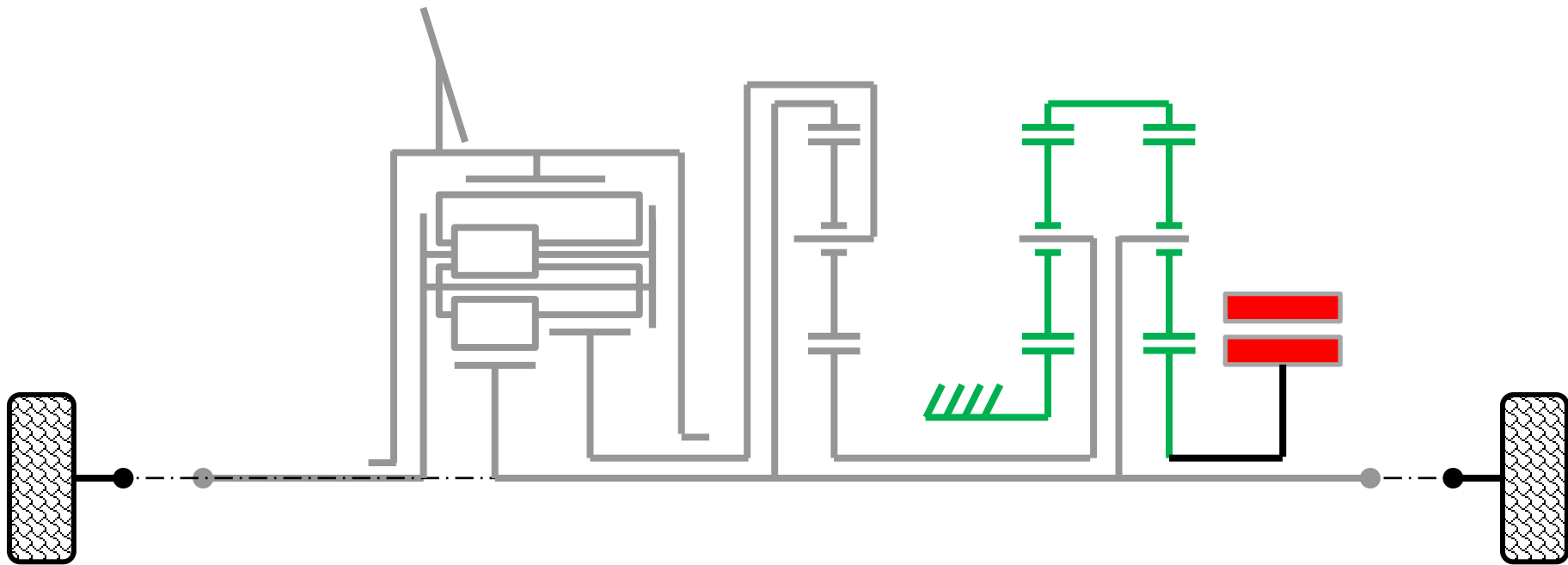


$$i_{TV} = \frac{\Delta T}{T_{EM}} = \frac{320 - (-320)}{10} = 64$$



# Torque Vectoring Topologies

## 2x Amplifying gear








■ Shafts / gears with speed of wheels





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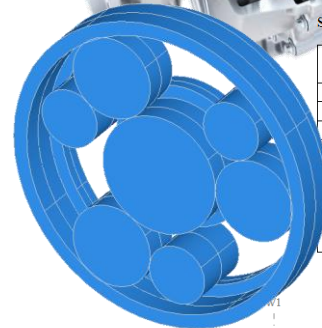
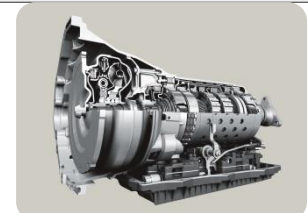
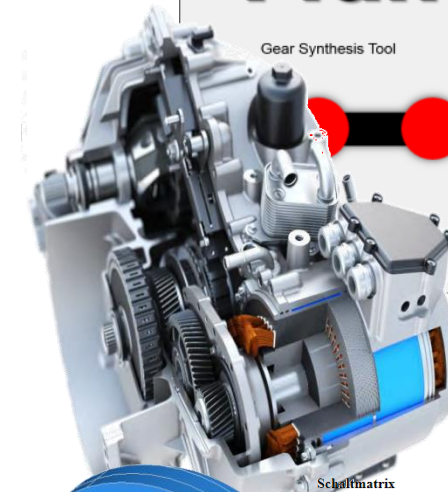
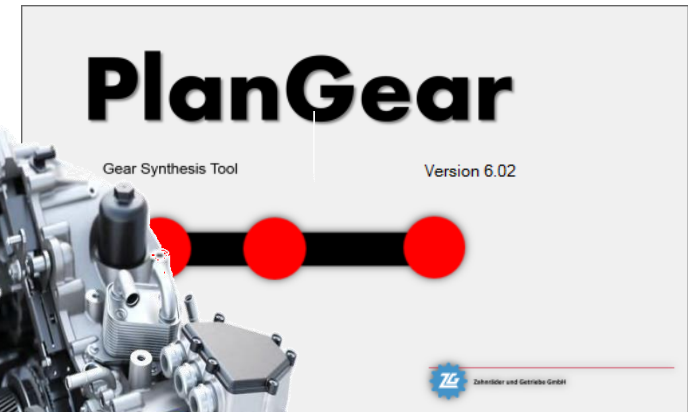
# PlanGear – Synthesis Program Overview and Features

Gear synthesis is the systematic approach of a gear structure with given boundary conditions

ZG is developing its own synthesis tool „PlanGear“ since 2010.

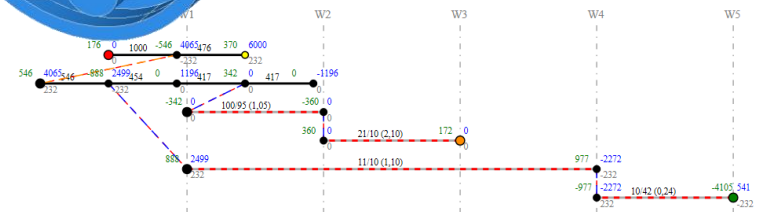
PlanGear is used for generation of gear structures:

- **Simple** and **complex compound** gear sets (e.g. Ravigneaux)
- Transmissions with **any number of shafts** (connected by spur gear stages)
- **AT** and **DCT** (and also crosses between both types → **MCT**)
- Conventional transmissions and hybrid powertrain structures (2 drives, ICE and EM)
- **Torque Vectoring** topologies with hybrid functions



Schaltmatrix

Gang	Schaltelement Nr. (Kopplungsnr.)					i	φ
	1 (25)	2 (27)	3 (79)	4 (90)	5 (95)		
1. Gang	X	X	X			5,000	∅
2. Gang	X	X		X		3,201	1,562
3. Gang		X	X	X		2,143	1,494
4. Gang		X		X	X	1,720	1,246
5. Gang		X	X		X	1,314	1,309
6. Gang			X	X	X	1,000	1,314
7. Gang	X		X		X	0,822	1,216
8. Gang	X			X	X	0,640	1,284
9. Gang	X	X			X	-3,457	-

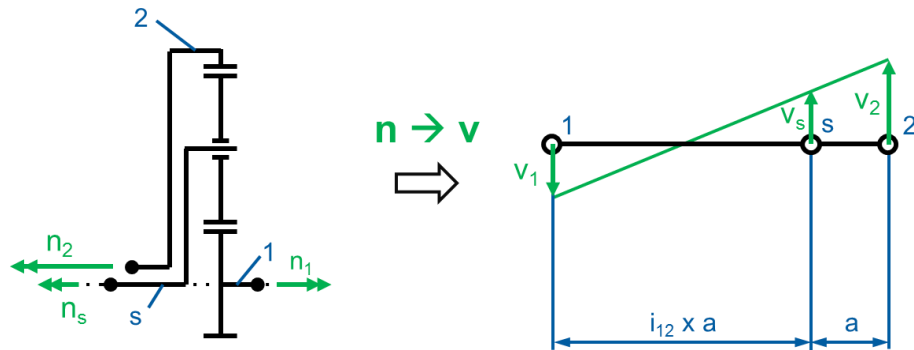




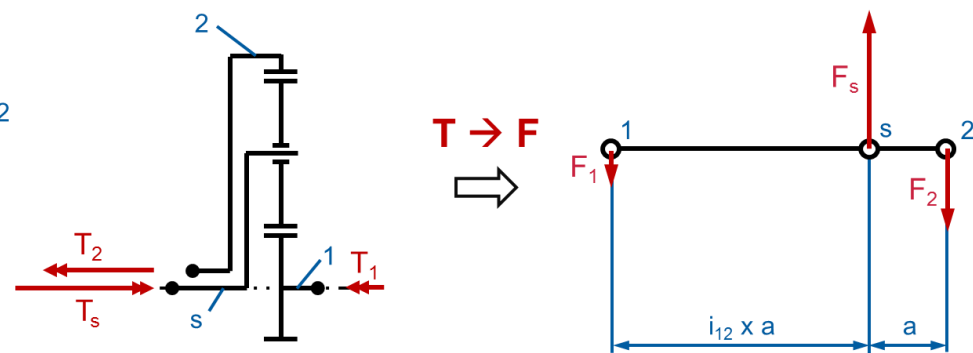
# PlanGear – Synthesis Program

## Analogy Model according to Helfer\*

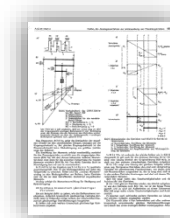
### Kinematic equivalence



### Static equivalence








\* Dipl.-Ing. F. Helfer:  
 Ein Analogieverfahren zur Untersuchung von Planetengetrieben, ATZ 69 (1967), S. 149-152





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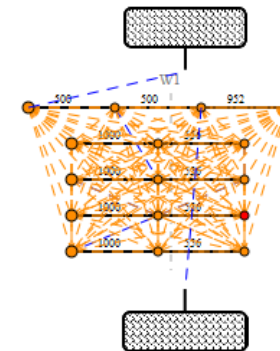
# Example

## Frame conditions for PlanGear

Note: Following demonstration example is any example. Clearly not best!

### Input data for PlanGear:

- Ratios: Gear 1: 14...35 - Parking / maneuvering
- Gear 2: 5...13 - 0...120 km/h
- Gear 3: 2...4 - 120...250 km/h
- TV:  $\Delta T_{max} / T_{EM} = 20...25$



- 1. SE (1/1 | 33)
- 2. SE (1/2 | 34)
- 3. SE (1/3 | 35)
- 4. SE (1/4 | 36)
- 5. SE (2/1 | 37)
- 6. SE (2/2 | 38)
- 7. SE (2/3 | 39)
- 8. SE (3/1 | 40)
- 9. SE (3/2 | 41)
- 10. SE (3/3 | 42)
- 11. SE (3/4 | 43)

- 132. Gehäuserverbindung (4/5 | 45)
- 133. Wellenverbindung (1,2->3 | 70)
- 134. Wellenverbindung (2,3->3 | 126)
- 135. Wellenverbindung (3/1->4 | 136)
- 136. Wellenverbindung (3/3->1 | 151)

Übersetzungsvorgabe des Primärtriebs

#	R(TV)	Absolut	i_min	i_max	phi_min	phi_max
1	<input type="checkbox"/>	<input checked="" type="checkbox"/>	14	35	/	/
2	<input type="checkbox"/>	<input checked="" type="checkbox"/>	5	13	1,1	5
3	<input type="checkbox"/>	<input checked="" type="checkbox"/>	2	4	1,1	5
4	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	0,5	2	1,2	10
*	<input type="checkbox"/>	<input type="checkbox"/>				



# Example

## List of results

Drucken

Ausgabe Skizze Sekundärantrieb Fahranalyse

HTML CSV

Syn I Syn II

Ausgabe List Alle Filter löschen

Loesungsnummer	Solution-ID	Getriebe-ID	Mechanik-ID	Kinematik-ID	Belastungs-ID	Strukturnummer	Baubar	Entflechtbar	Schaltbarkeit(N)	Anzahl Balken	P Blk 1
1	FA-B8-B3-48-AE...	3D-42-CB-32-62...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
2	25-15-7B-B8-8C...	15-47-29-3E-9C-5...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
3	AD-A6-4F-35-F6...	C4-72-E7-D8-A4...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
4	E3-90-C6-10-F1...	C5-99-AF-D2-58...	E0-51-EC-2E-01...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
5	30-47-D2-FB-D7...	EC-3F-68-7D-75...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
6	07-F1-8B-C6-62-6...	4C-DD-3F-3C-E8...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
7	E6-E2-B8-1A-91...	FB-BA-FD-7A-E4...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
8	F8-05-07-F7-76-0...	B7-0A-89-B9-82...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	C9-64-7B-65-D9...	11_17_457092...	True	False	True	5	500
9	08-AD-FE-90-07...	14-E4-26-94-66-A...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	18-68-05-0D-D7...	11_17_457092...	True	False	True	5	500
10	65-A3-89-14-C7...	36-33-02-60-41-E...	17-34-64-82-AC-8...	81-08-9C-A5-07...	25-C6-25-B4-1E...	11_17_457092...	True	False	True	5	500
11	E8-9F-92-08-95-1...	94-77-16-97-BD...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	C9-64-7B-65-D9...	11_17_457092...	True	False	True	5	500
12	F2-C5-42-D1-05...	FA-20-4B-9C-26...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
13	C8-A5-92-99-78-4...	26-CA-04-74-D5...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
14	76-02-5B-A9-8A...	93-1F-D1-E7-95...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	18-68-05-0D-D7...	11_17_457092...	True	False	True	5	500
15	3D-82-D2-2F-73...	5A-D6-03-25-69...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
16	0A-31-A7-6F-57-9...	E8-17-EA-92-98...	17-34-64-82-AC-8...	81-08-9C-A5-07...	25-C6-25-B4-1E...	11_17_457092...	True	False	True	5	500
17	F2-00-F3-7C-55-C...	0E-9A-F6-DF-25...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
18	24-B8-07-F5-B2-5...	EF-CE-17-BD-93...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
19	97-F2-E1-28-0D...	E2-EE-91-43-38...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
20	AF-5D-37-E6-34...	A9-34-73-07-27-9...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
21	0E-AB-43-A4-03...	CA-65-F2-4A-70...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
22	2C-09-9F-59-9C-2...	DA-88-B2-D0-D8...	2E-99-91-9C-0D...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
23	A9-34-0A-4E-59...	B7-F4-C4-25-39-9...	E0-51-EC-2E-01...	81-08-9C-A5-07...	8C-99-B7-60-68-1...	11_17_457092...	True	False	True	5	500
24	2F-95-08-6A-95-2...	72-E2-01-B1-E0...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
25	48-57-49-CC-5A...	F8-86-1A-2C-34-8...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
26	0A-B8-D4-A2-87...	4C-96-79-C6-FD...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
27	79-0D-92-C7-1C...	D4-69-7E-67-6D...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	C9-64-7B-65-D9...	11_17_457092...	True	False	True	5	500
28	AB-37-FE-6F-E1...	A9-2A-BE-AE-41...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	18-68-05-0D-D7...	11_17_457092...	True	False	True	5	500
29	65-FD-43-87-4C...	C5-DF-3A-C7-32...	17-34-64-82-AC-8...	81-08-9C-A5-07...	25-C6-25-B4-1E...	11_17_457092...	True	False	True	5	500
30	AC-FD-5C-A8-24...	5C-2D-E9-74-A3...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	C9-64-7B-65-D9...	11_17_457092...	True	False	True	5	500
31	84-34-59-73-BA-8...	8C-0D-64-C6-57...	F9-9B-FC-7B-58...	81-08-9C-A5-07...	1A-57-C5-A8-E4...	11_17_457092...	True	False	True	5	500
32	04-B8-59-30-9E...	8A-DD-7A-B3-45...	0C-8D-B5-AB-3F...	81-08-9C-A5-07...	18-68-05-0D-D7...	11_17_457092...	True	False	True	5	500

Filterable excel list

Speichern Drucken Template GearBuild

Ausgehende Lösungen

Alle

Lösungen

Aktuelle Lösung

Dateiformat der Ausgabe

\*.csv-Format(Reduziert)

Weitere Optionen

Max. Anzahl der Schalte

Speichern

Syntheschritt II

Durchführen

Elementargetriebe / Kopp...

Reduzierte Koppelsätze

Optionen zur Baubarkeit

Graph erstellen...

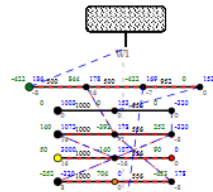
Snipping Tool



# Example

## Developing results in PlanGear

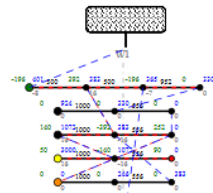
Gang 1



- 1. SE (2 | 47)  $\alpha = 0,00$  -  $T = -14,09$
- 2. SE (2 | 46)  $\alpha = 0,21$  -  $T = 0,00$
- 3. SE (2 | 65)  $\alpha = 0,26$  -  $T = 0,00$
- 4. SE (2 | 37)  $\alpha = 0,31$  -  $T = 0,00$

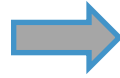
- 5. Geküßelverbindung (2 | 46)  $T = -1,30$
- 6. Willenverbindung (2 | 46 | 2 | 70)  $T = 0,83$
- 7. Willenverbindung (2 | 46 | 2 | 126)  $T = 0,00$
- 8. Willenverbindung (2 | 46 | 2 | 136)  $T = -2,30$
- 9. Willenverbindung (2 | 46 | 2 | 141)  $T = 0,00$
- 10. Willenverbindung (2 | 46 | 2 | 147)  $T = 0,00$
- 11. Willenverbindung (2 | 46 | 2 | 147)  $T = 4,00$

Gang 2

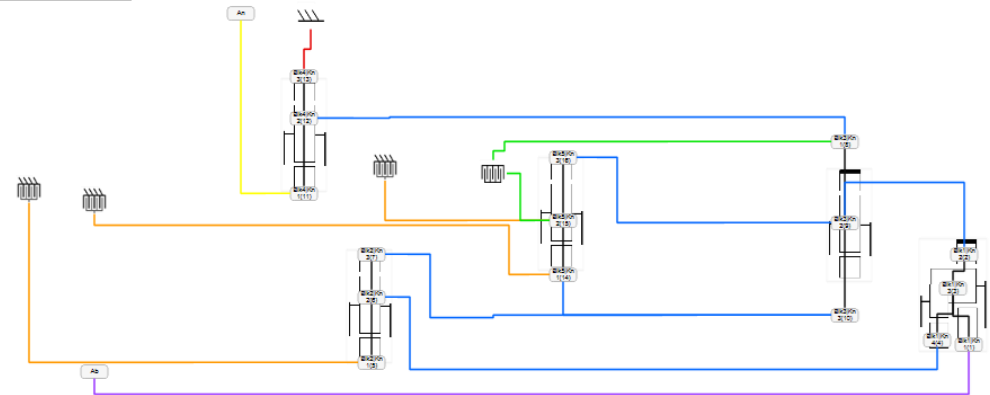


- 1. SE (2 | 47)  $\alpha = 0,00$  -  $T = 0,00$
- 2. SE (2 | 46)  $\alpha = 0,00$  -  $T = -0,09$
- 3. SE (2 | 65)  $\alpha = 0,21$  -  $T = 0,00$
- 4. SE (2 | 37)  $\alpha = 0,31$  -  $T = 0,00$

- 5. Geküßelverbindung (2 | 46)  $T = -1,30$
- 6. Willenverbindung (2 | 46 | 2 | 70)  $T = -7,81$
- 7. Willenverbindung (2 | 46 | 2 | 126)  $T = 0,00$
- 8. Willenverbindung (2 | 46 | 2 | 136)  $T = -2,30$
- 9. Willenverbindung (2 | 46 | 2 | 141)  $T = 0,00$
- 10. Willenverbindung (2 | 46 | 2 | 147)  $T = 0,00$
- 11. Willenverbindung (2 | 46 | 2 | 147)  $T = 0,00$

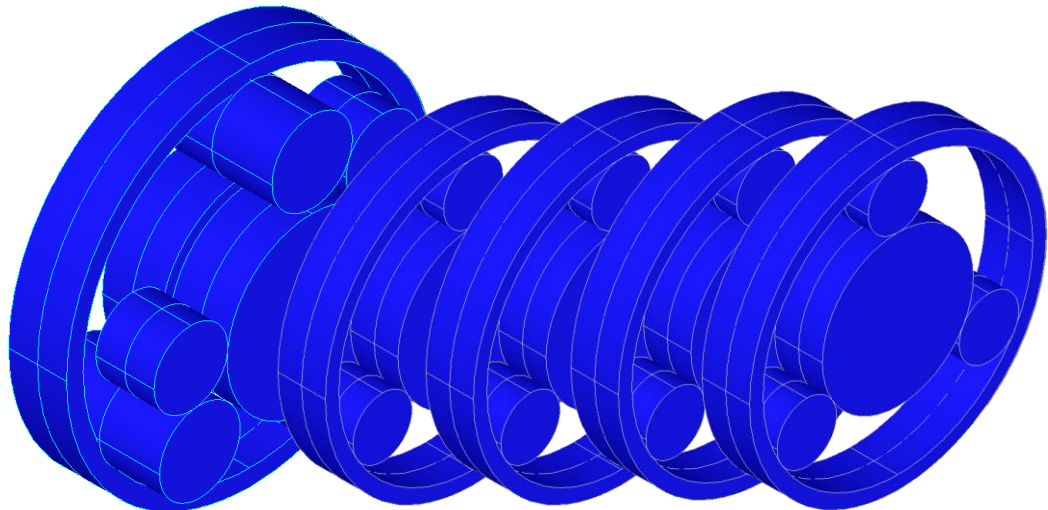


Zuletzt angeklickten Knoten in den Vordergrund verschieben  
Zuletzt angeklickten Knoten in den Hintergrund verschieben



Gear	Shift Element Nr. (Coupling Nr.)				i	$\varphi$
	1 (47)	2 (46)	3 (139)	4 (37)		
1. Gear	X				16,122	$\emptyset$
2. Gear		X			7,478	2,156
3. Gear			X		2,672	2,799
4. Gear				X	1,027	2,601

Gear	Shift Element Nr. (Coupling Nr.)				i	$\varphi$
	1 (47)	2 (46)	3 (139)	4 (37)		
1. Gear	-14,086	-0,107	0,357	0,334	16,122	$\emptyset$
2. Gear	0,082	-5,033	0,275	0,308	7,478	2,156
3. Gear	0,357	0,357	2,335	0,219	2,672	2,799
4. Gear	1,036	1,238	-0,678	2,799	1,027	2,601

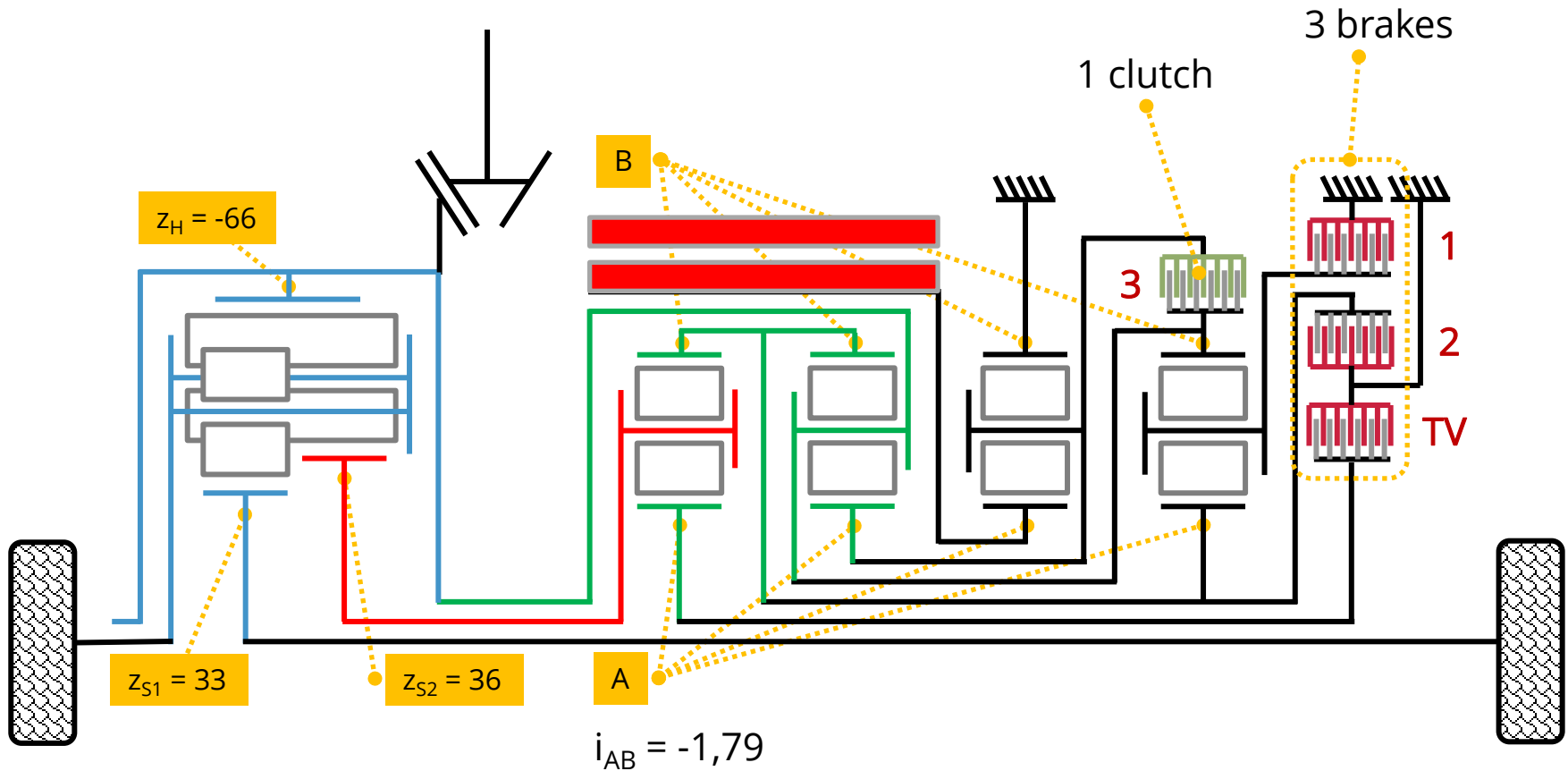




# Example

## Possible topology with 5 planetary gears

! Demonstration example - better solutions possible !

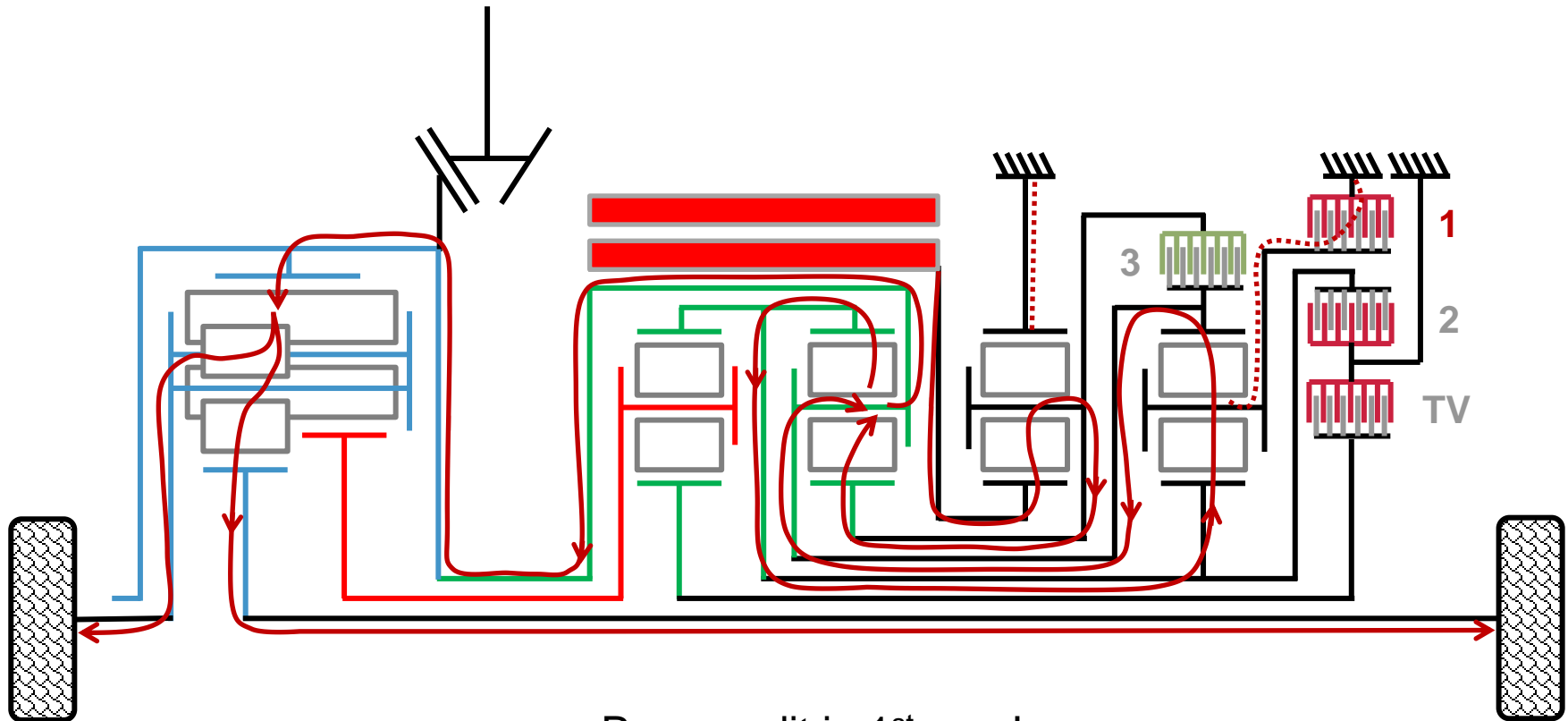




# Example

## Power flow – 1<sup>st</sup> Gear

! Demonstration example – better solutions possible !



Power split in 1<sup>st</sup> gear!

$$i_1 = 16,12$$

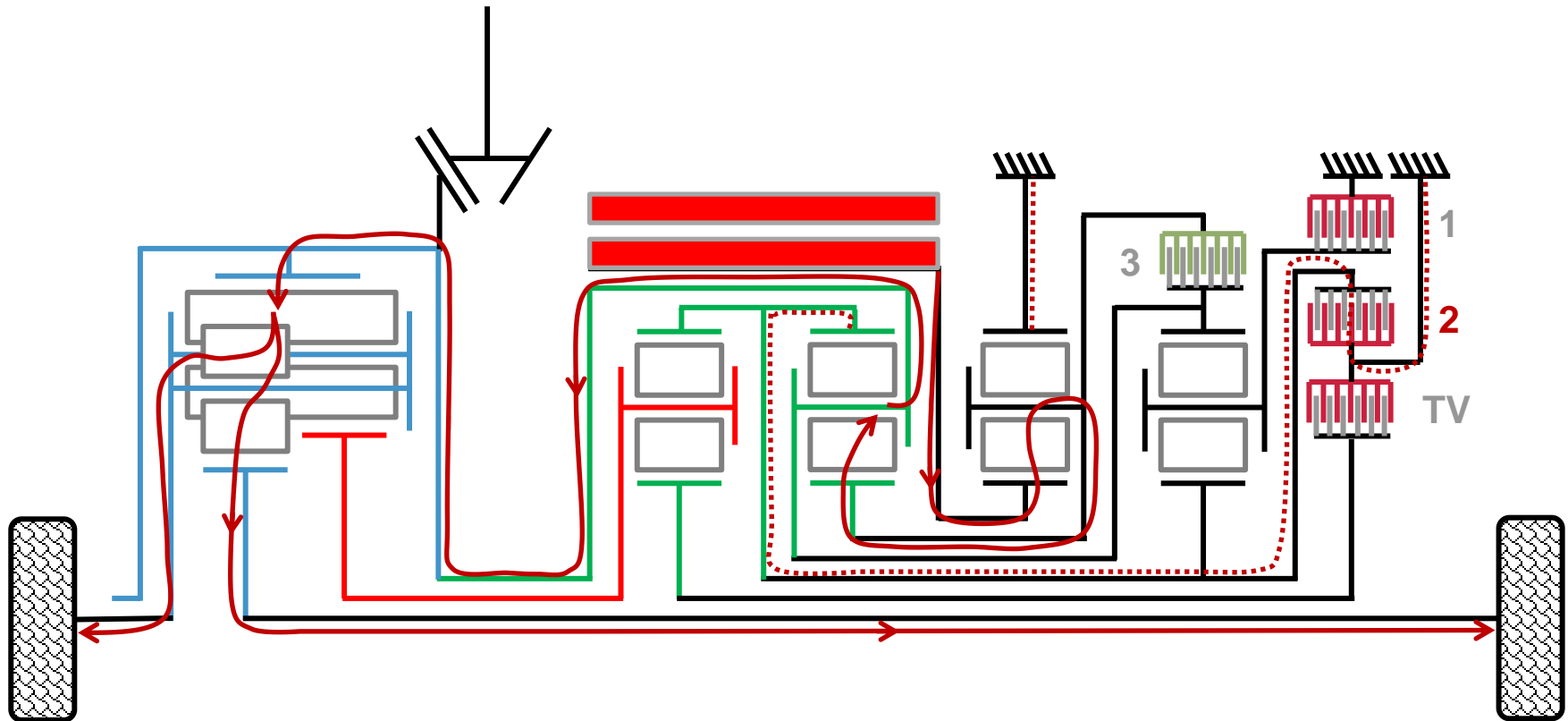




# Example

## Power flow – 2<sup>nd</sup> Gear

! Demonstration example – better solutions possible !



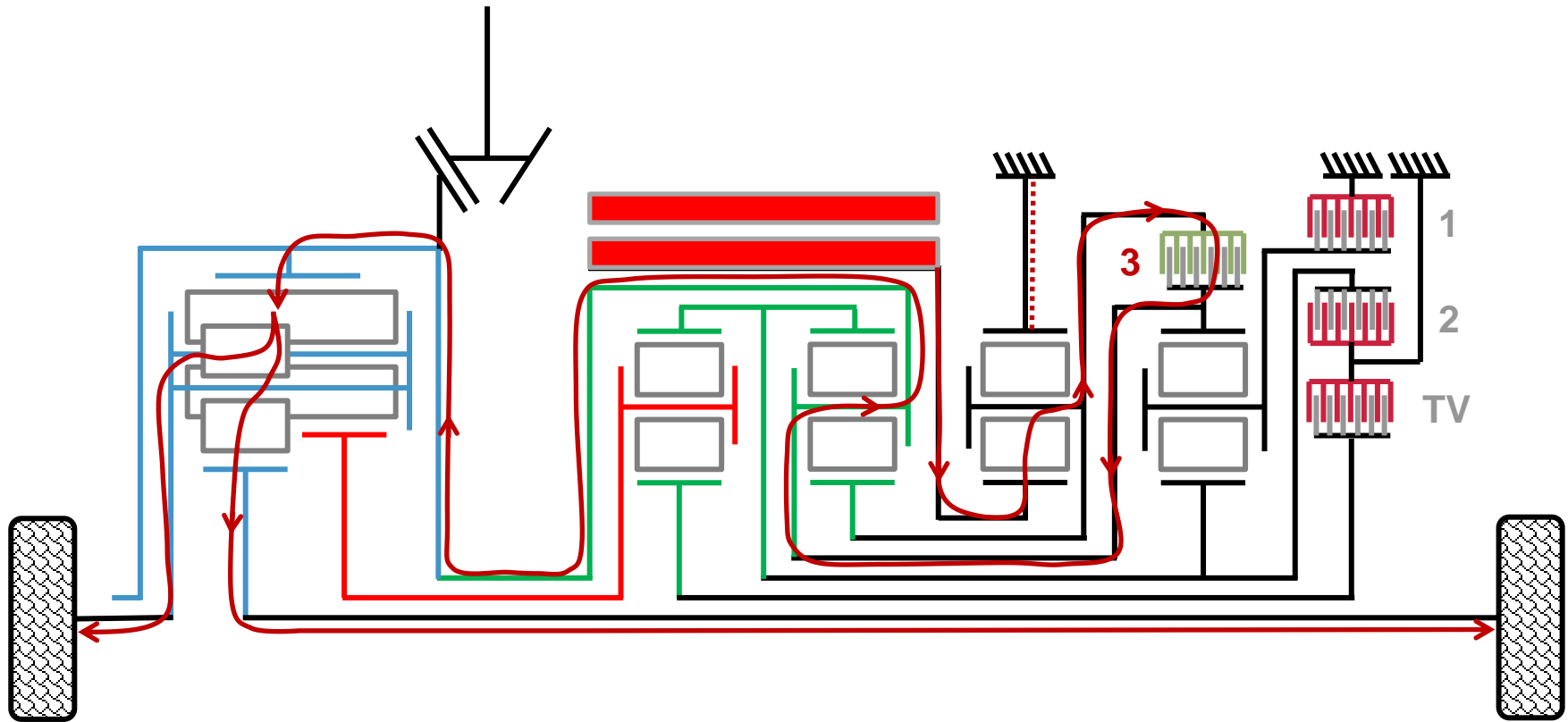
$$i_2 = 7,48$$



# Example

## Power flow – 3<sup>rd</sup> Gear

! Demonstration example – better solutions possible !



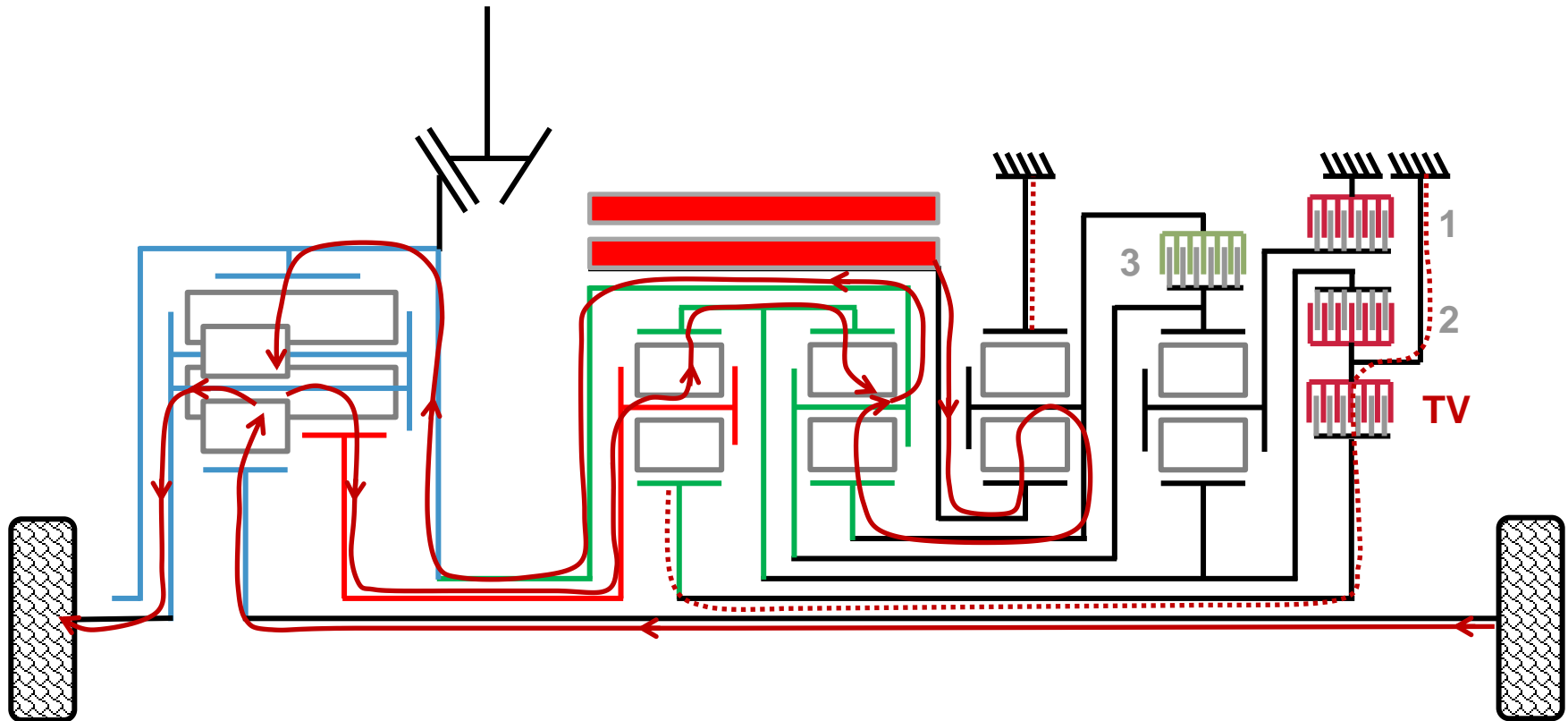
$$i_3 = 2,67$$



# Example

## Power flow – Torque Vectoring

! Demonstration example – better solutions possible !

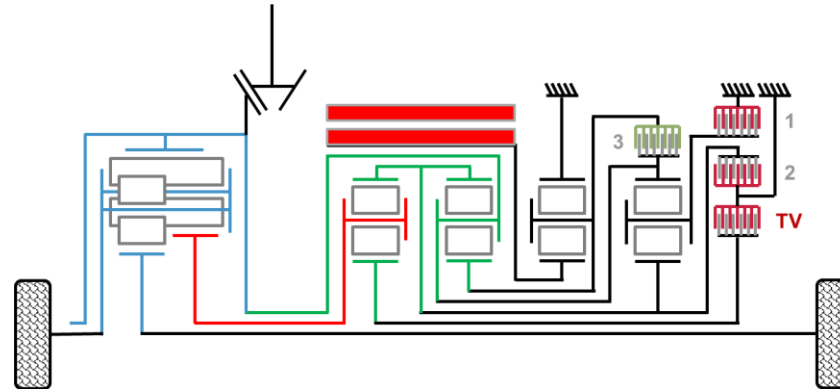


$$\Delta T_{Wheels} / T_{EM} = 22,76$$



# Example

## Efficiency grades



Primary Input				
Option RS(1)-KS(1)-KS(1)-KS(1)-KS(1)				
Feasible				
Gear	1	2	3	4
Efficiency [%]	92,0	94,8	97,3	100,0
Power losses [kW]	0,7	0,4	0,2	1,9
Bearing speed [l/min]	4826	4826	4826	5975






→ Load dependent mesh losses considered (defined operation mode)

→ Internal gears:  $\eta_{vz} = 99,5\%$

→ External gears:  $\eta_{vz} = 98,5\%$



# Content

-  Overview
-  Basic Principle of Torque Vectoring with Superimposing Unit
-  PlanGear – Synthesis Program
-  Example
-  Summary



# Summary

- General principles of torque vectoring (TV) with superimposing units were shown.
- Amplifying planetary gears lead to increased TV-ratios and reduced torques on superimposing gears (→ reduced weight).
- Gear synthesis program “PlanGear” was enabled to calculate torque vectoring structures in combination with hybrid functionalities.
- An example topology generated by PlanGear was explained:
  - Inline arrangement of 5 planetary gears including 1 Ravigneaux gear set.
  - 3 gears for hybrid functionalities over whole speed range of the car.
  - 1 torque vectoring gear for whole speed range.
  - High efficiency in all operating modes.
  - Disc clutches and brakes for fast, reliable and comfortable gear shifts.