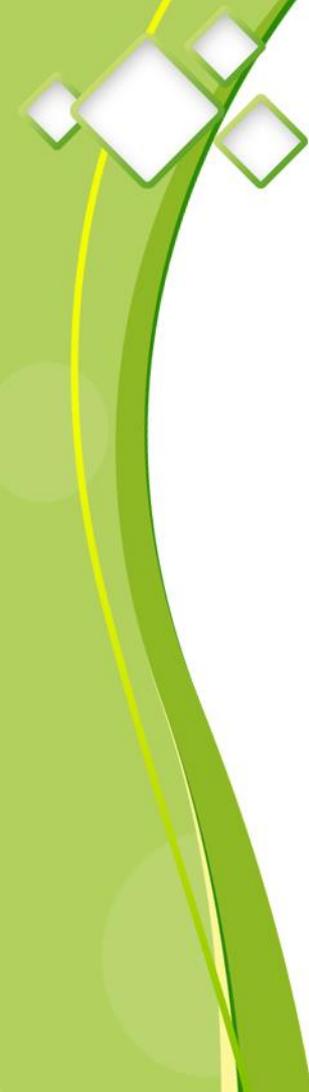




압전소자를 이용한  
충전식 타이어

Re 타이어

엄지환 신진호 최영주



# Contents

## Part I

- 1 Energy Harvesting
- 2 압전효과
- 3 Introduction

## Part II

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- 2 Piezoelectric 해석

## Part III

- 1 배터리 SOC 해석
- 2 결과 & 결론
- 3 Q&A



## Part I

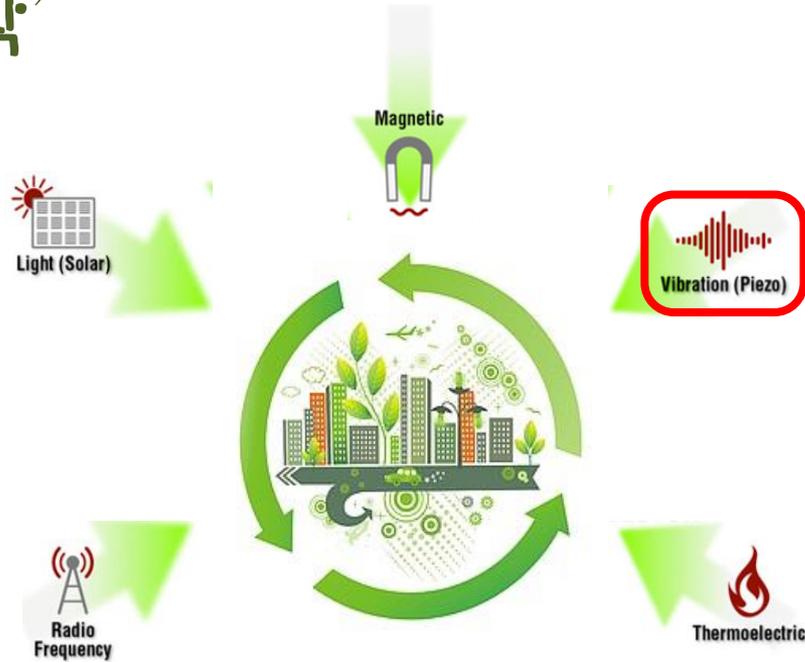
1 Energy Harvesting

2 압전효과

3 Introduction

# 1 Energy Harvesting

‘스마트’



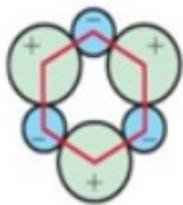
# 1 Energy Harvesting



Energy Harvesting (Piezo) + Tire

## 2 압전효과

정상상태

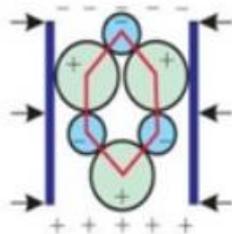


압력, 충격

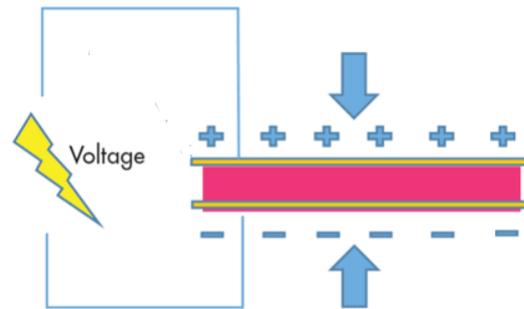


Mechanical  
Energy

압축력이  
가해졌을 때



Electrical  
Energy



$$Q_x = d_{11} F_x$$

$$V = \frac{Q_x}{C} = \frac{d_{11}}{C} F_x$$

# 3 Introduction

1) Tire



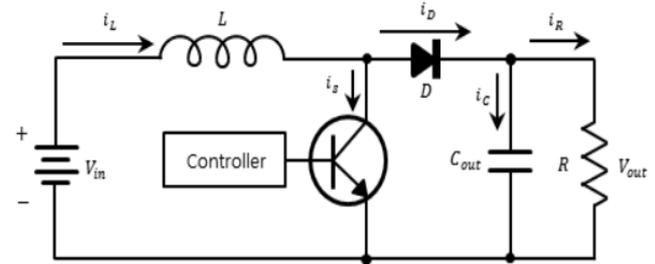
압력  
집속면전

2) Piezo

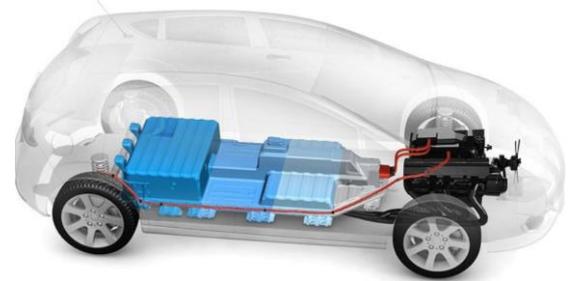


Voltage Power

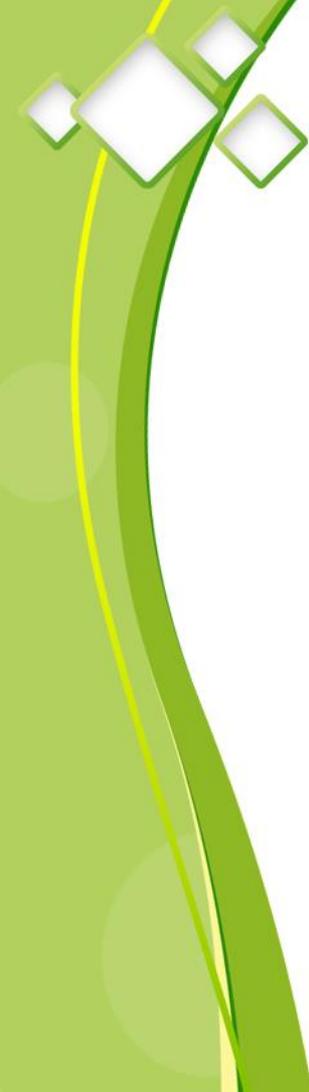
3) Battery



DC-DC Converter



Battery SOC



## Part II

1 타이어의 압력 해석

2 Piezoelectric 해석

# 1 타이어의 압력 해석

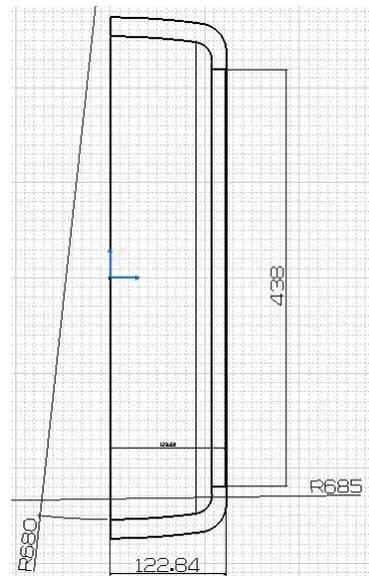
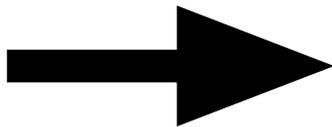
## 1) Modeling



Vehicle model : Tesla model S

# 1 타이어의 압력 해석

## 1) Modeling



quarter model로 효율적인 해석

245/45R19

# 1 타이어의 압력 해석

## 1) Modeling



Hyperelastic material

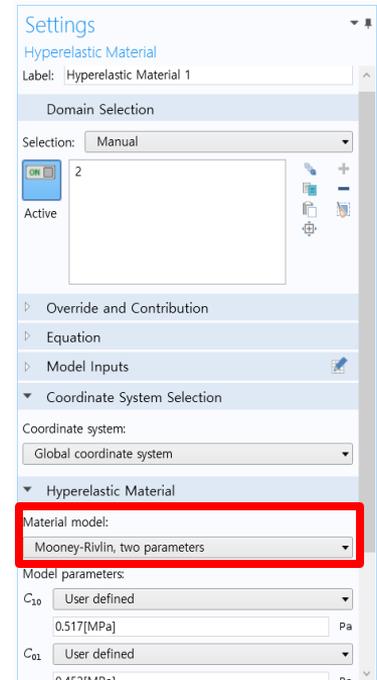
비선형 해석 : Mooney-Rivlin model

$$0 \equiv \nabla \cdot \mathbf{F} \mathbf{S} + \mathbf{F} \mathbf{v}, \quad \mathbf{F} = \mathbf{I} + \nabla \mathbf{u}$$

$$\mathbf{S} = \mathbf{S}_{\text{ext}} + \frac{\partial W_s}{\partial \boldsymbol{\epsilon}}, \quad \boldsymbol{\sigma} = J^{-1} \mathbf{F} \mathbf{S} \mathbf{F}^T, \quad J = \det(\mathbf{F})$$

$$\boldsymbol{\epsilon} = \frac{1}{2}(\mathbf{F}^T \mathbf{F} - \mathbf{I})$$

$$W_s = C_{10}(\bar{I}_1 - 3) + C_{01}(\bar{I}_2 - 3) + \frac{1}{2} \kappa (J_{\text{el}} - 1)^2$$



# 1 타이어의 압력 해석

## 1) Modeling

- Linear Elastic Material 1
    - Free 1
    - Initial Values 1
    - Fixed Constraint
    - tire\_hyperelastic
    - quarter\_roller
    - Contact 1
    - Contact 2
    - Prescribed Displacement 2
    - vehicle\_load
    - air\_pressure
    - Equation View

constrains

→ 지면을 fix

→ 타이어 재질반영

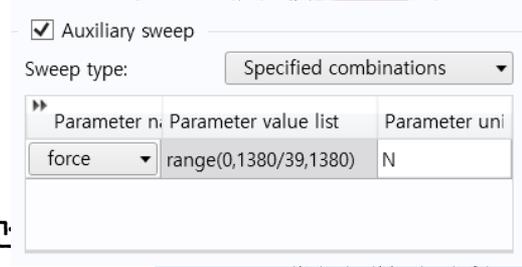
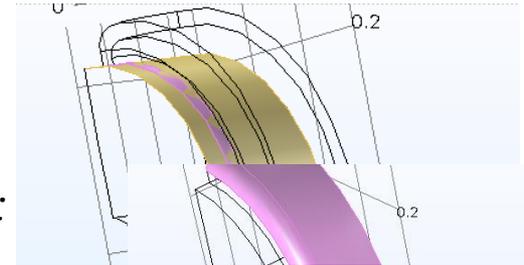
→ quarter modeling을 위한  
roller 조건

→ 타이어&휠 접촉조건

→ 타이어&지면 접촉조건

→ 차량의 무게 :  
(2250\*9.81/4)

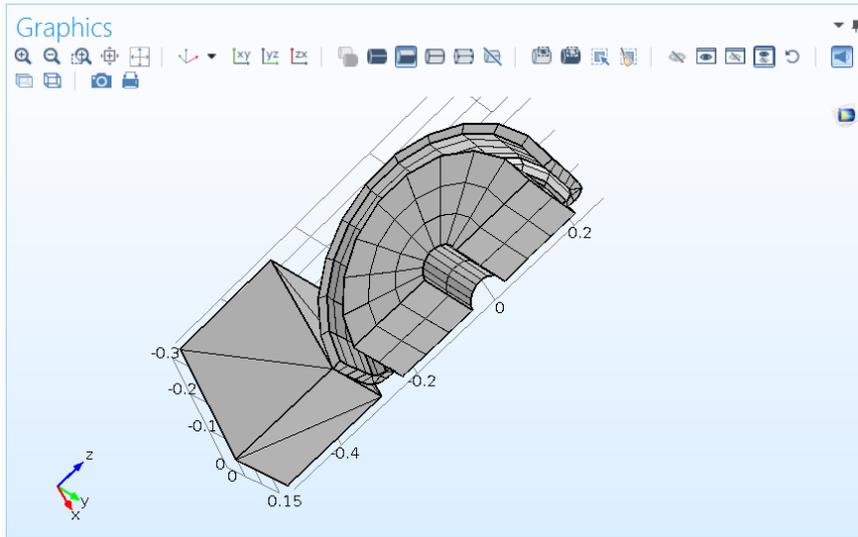
→ 타이어의 공기압  
(36psi = 0.24821 [MPa])



# 1 타이어의 압력 해석

## 1) Modeling

Mesh



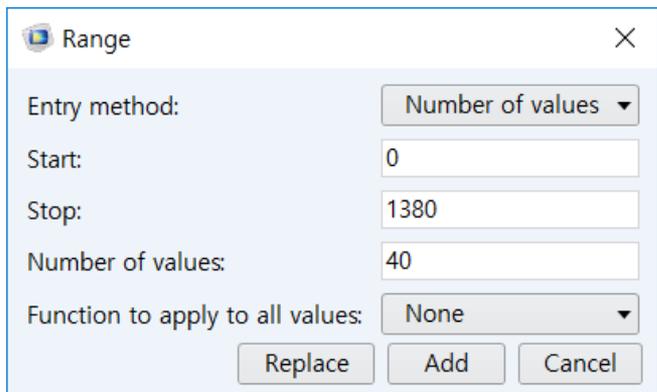
비선형 해석 : 계산시간 ↑

coarse하게 Mesh 생성

# 1 타이어의 압력 해석

## 1) Modeling

Nonlinear solving



Range

Entry method: Number of values

Start: 0

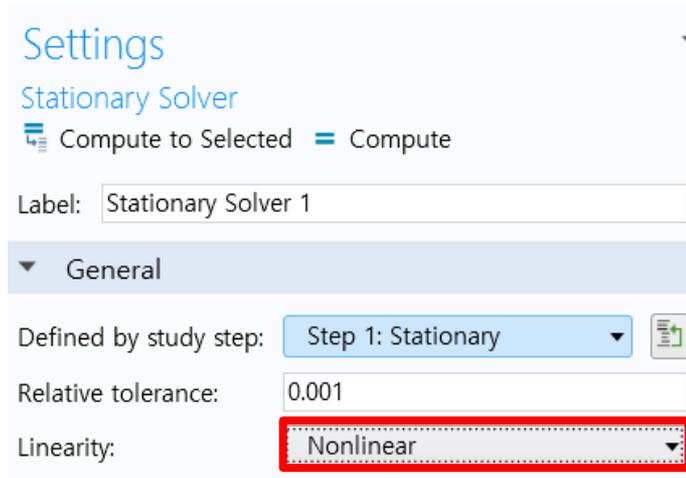
Stop: 1380

Number of values: 40

Function to apply to all values: None

Replace Add Cancel

auxiliary sweep : force 값을  
40등분하여 solve



Settings

Stationary Solver

Compute to Selected Compute

Label: Stationary Solver 1

General

Defined by study step: Step 1: Stationary

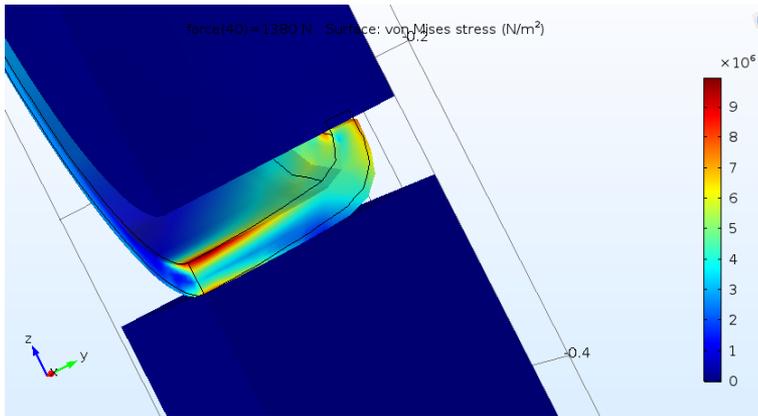
Relative tolerance: 0.001

Linearity: Nonlinear

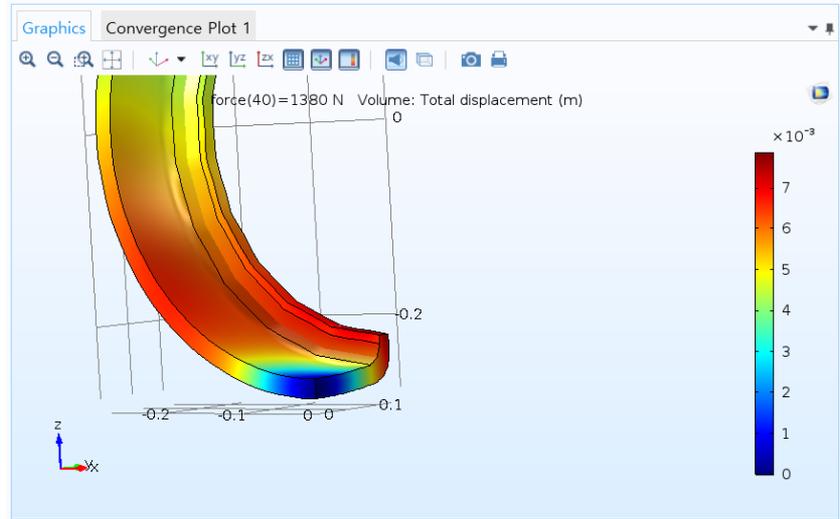
Linearity를 Nonlinear로 선택

# 1 타이어의 압력 해석

## 2) Analysis



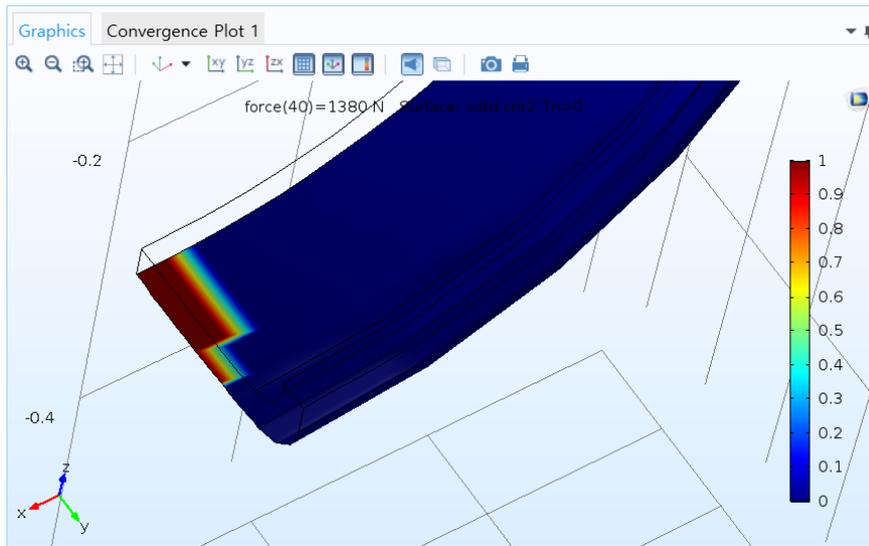
Load에 의한 변형,  
Von Mises stress



displacement

# 1 타이어의 압력 해석

## 2) Analysis

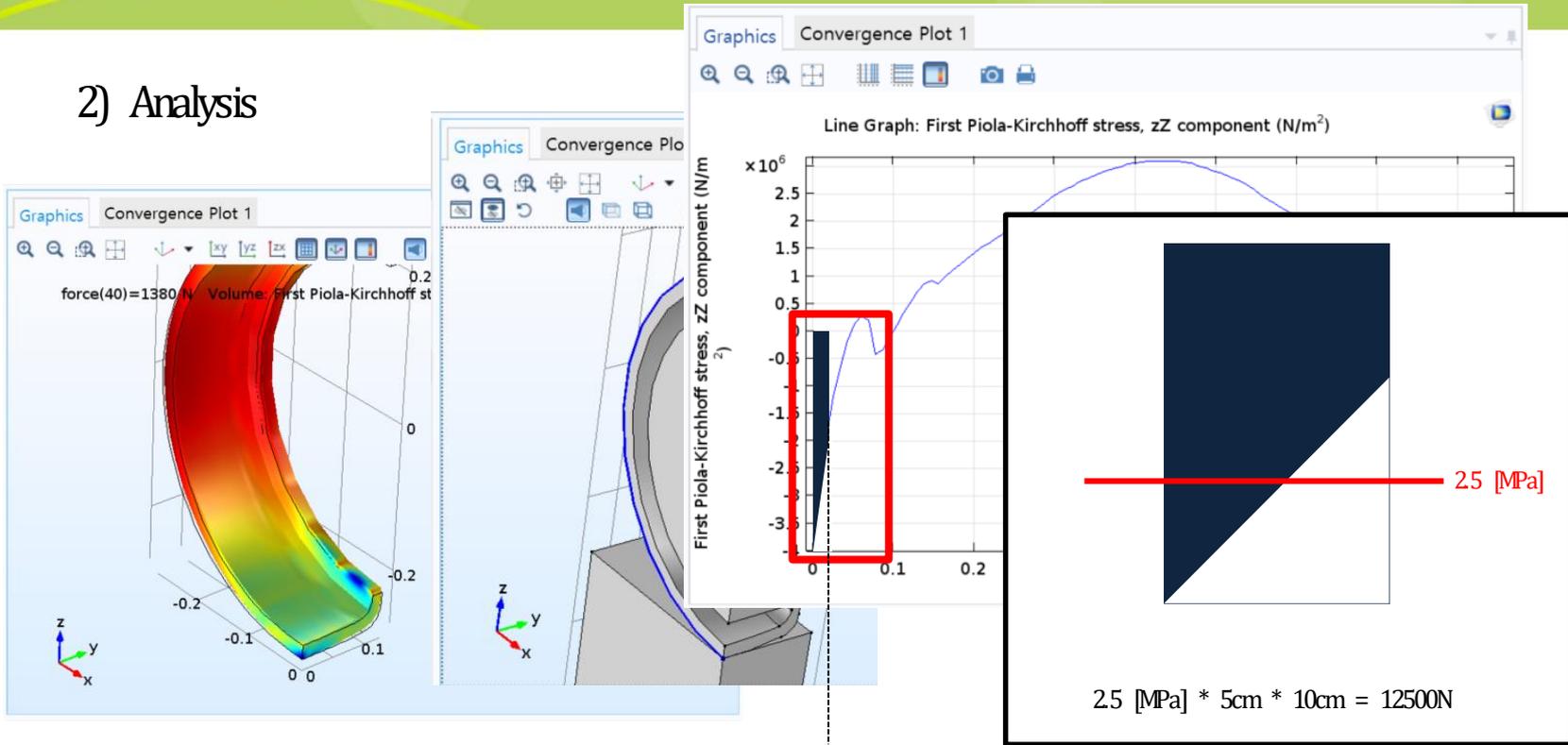


force (N)	solid.cnt2.Tn>0 (m <sup>2</sup> )
1203.1	0.0012213
1238.5	0.0012213
1273.8	0.0012213
1309.2	0.0012213
1344.6	0.0012213
1380.0	0.0012213

$$\begin{aligned}\text{Contact area} &= 12.21 \times 4 \\ &= 48.84 \text{ cm}^2\end{aligned}$$

# 1 타이어의 압력 해석

## 2) Analysis



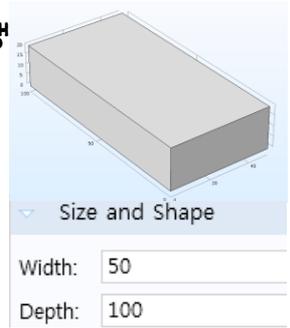
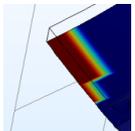
z방향의 응력을  
의

25cm

# 2 PiezoElectric 해석

## 1) Modeling

- Geometry 1
      - Block 1 (*blk1*) → 타이어의 접촉면적 만큼 피에조 형상 생
      - Form Union (*fin*)
    - Materials
      - Lead Zirconate Titanate (PZT-4) (*mat1*) → 피에조 물성
    - Solid Mechanics (*solid*)
      - Linear Elastic Material 1
      - Free 1
      - Initial Values 1
      - Piezoelectric Material 1
      - Fixed Constraint 1
      - Boundary Load 1 → 타이어의 응력  $F_{Tot}$ 
        - Equation View
        - Load type: Total force
        - 0
        - 0
        - F
    - Electrostatics (*es*)
      - Charge Conservation 1
        - Zero Charge 1 → 옆면은 Zero Charge, 아랫면은 Ground
        - Initial Values 1
        - Charge Conservation, Piezoelectric 1 → 윗면을 Floating면으로 지정
        - Ground 1
        - Floating Potential 1
    - Multiphysics
    - Mesh 1

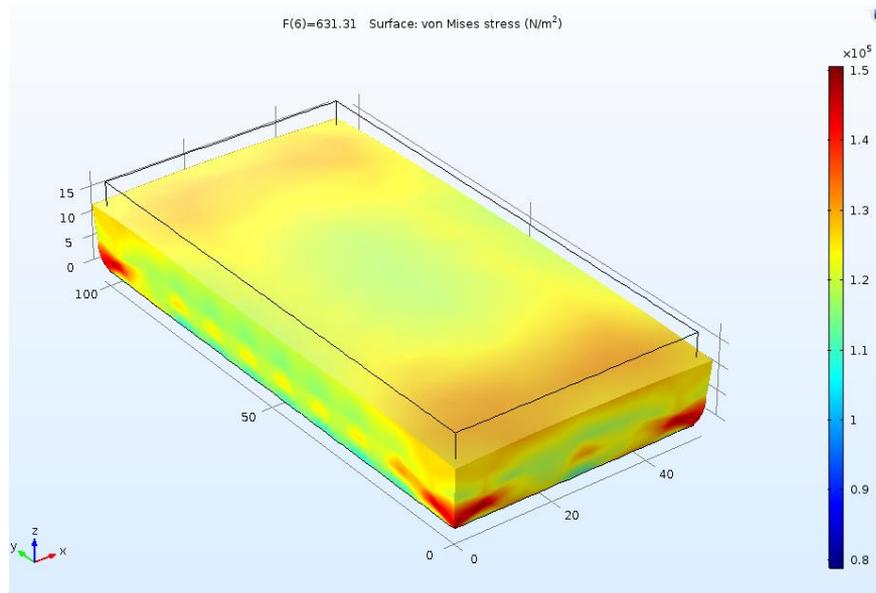


# 2 PiezoElectric 해석

## 2) Analysis

- Results
  - Data Sets
  - Views
  - Derived Values
    - Point Probe Expression 1
  - Tables
  - Stress (solid)
    - Surface 1
  - Electric Potential (es)
  - Probe Plot Floating potential(V)
    - Probe Table Graph 1
  - 3D Plot Group 7
  - 1D Plot Impedance
    - Global 1

-Stress

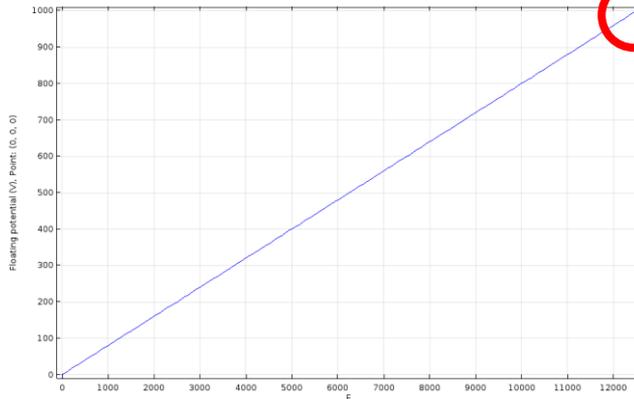


# 2 PiezoElectric 해석

## 2) Analysis

- Results
  - Data Sets
  - Views
    - Derived Values
      - Point Probe Expression 1
    - Tables
    - Stress (solid)
      - Surface 1
    - Electric Potential (es)
      - Probe Plot Floating potential(V)
      - Probe Table Graph 1
    - 3D Plot Group 7
    - 1D Plot Impedance
      - Global 1

-Floating potential (V)



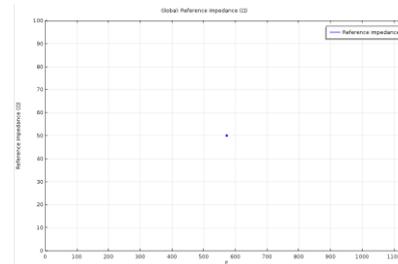
F	Floating potential (V), Point: (0, 0, 0)
12121	969.91
12247	980.02
12374	990.12
12500	1000.2

1000.2 V

4 wheel  $\div$  4000 V

-Impedance ( $\Omega$ )

50  $\Omega$





## Part III

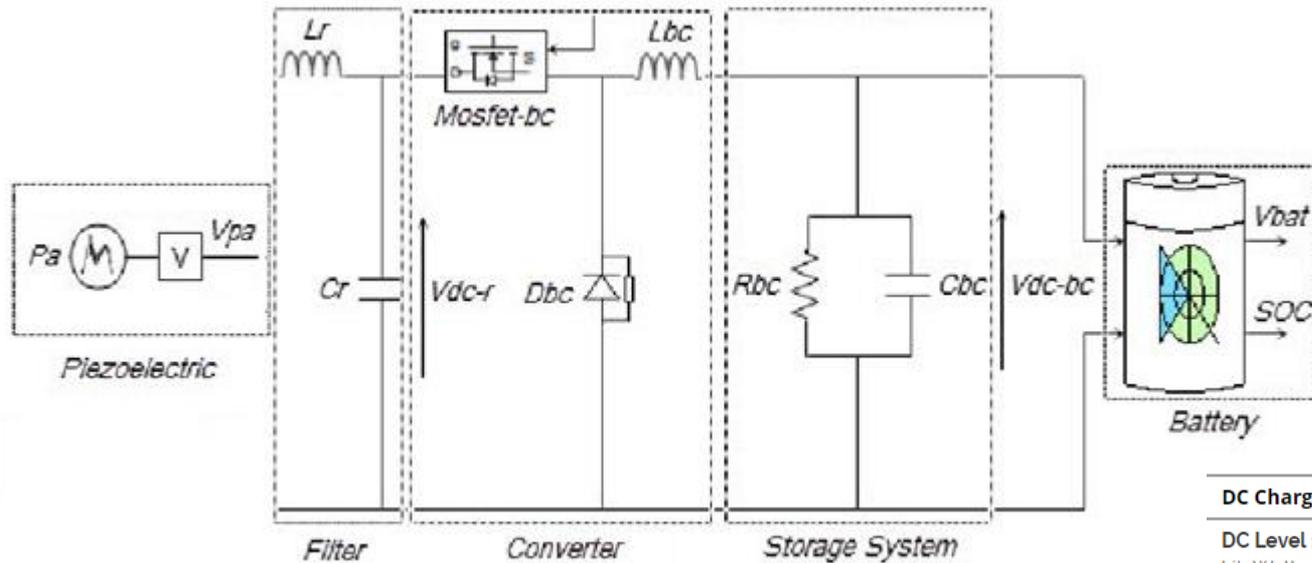
1 배터리 SOC 해석

2 결과 & 결론

3 고찰

# 1 배터리 SOC 해석

## Modeling Outline



### SAE's "Level 1/2/3"

#### DC Charging Systems

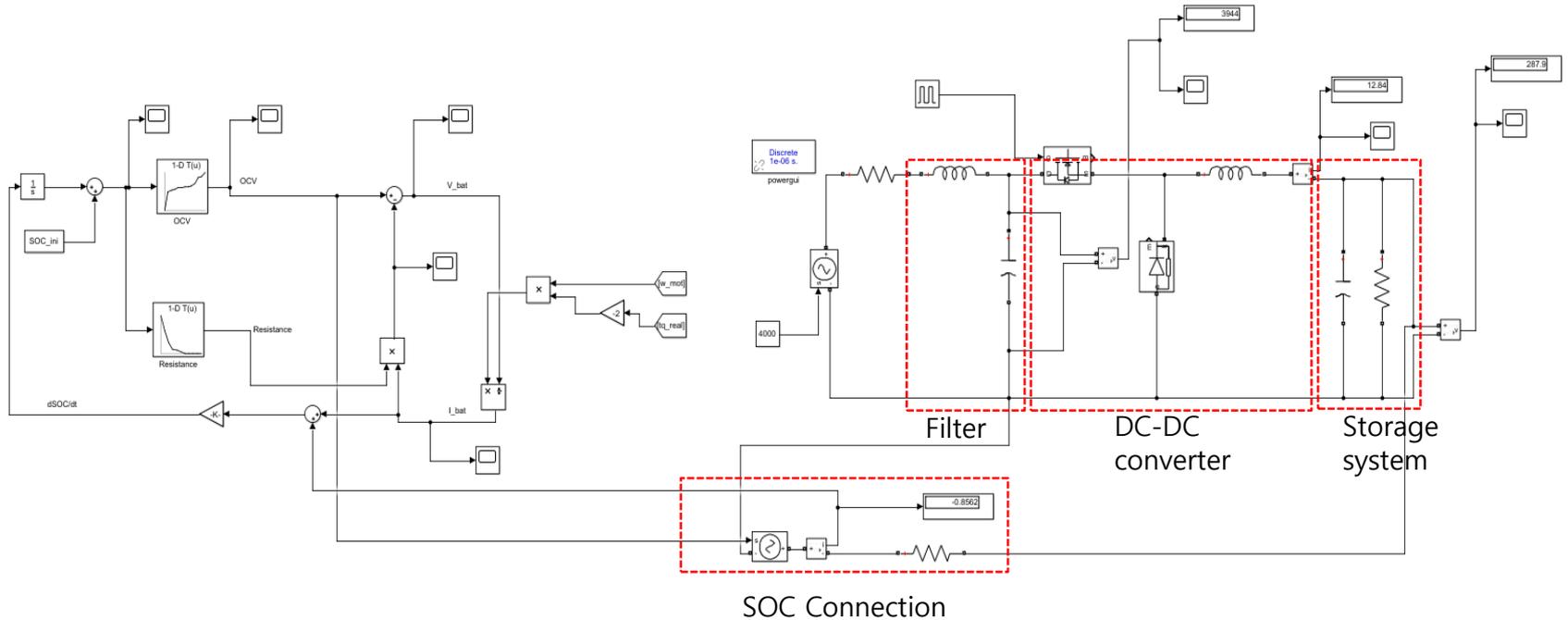
**DC Level 1:** 200-450 volts DC up to 36 kiloWatts (80A)

**DC Level 2:** 200-450 volts DC up to 90 kiloWatts (200A)

**DC Level 3:** 200-600 volts DC up to 240 kiloWatts (400A)

# 1 배터리 SOC 해석

## SOC Calculation



# 1 배터리 SOC 해석

[EV-Full model Simulink parameters]



**Tesla Model S**



**Powertrain**

**Electric motor** Front and rear motor combined output up to 779 bhp (581 kW), 920 lb-ft (1,250 N-m), 3-phase AC induction motor

**Transmission** 1-speed fixed gear (9.73:1)

**Battery** 100 kWh lithium ion

**Dimensions**

**Curb weight** 4,960 lb (2,250 kg) (P100D)

전	배터리 종류	리튬 이온
기	배터리 전압 (V)	350
	배터리 용량 (Ah)	290

**Tesla Model S Tire Sizes**

100D [245/45R19](#)

<b>motor maxim</b>	930Nm Ia 0-5.100 1/min
--------------------	---------------------------



vehicle\_data



Tq\_max

FGR = 9.73; % Gear Ratio

m = 2250; % Weight

OCV = 345  
C\_nom=290; % rated capacity [Ah]

R\_tire = 0.2413; % Tire radius - 19inch(0.4826m)

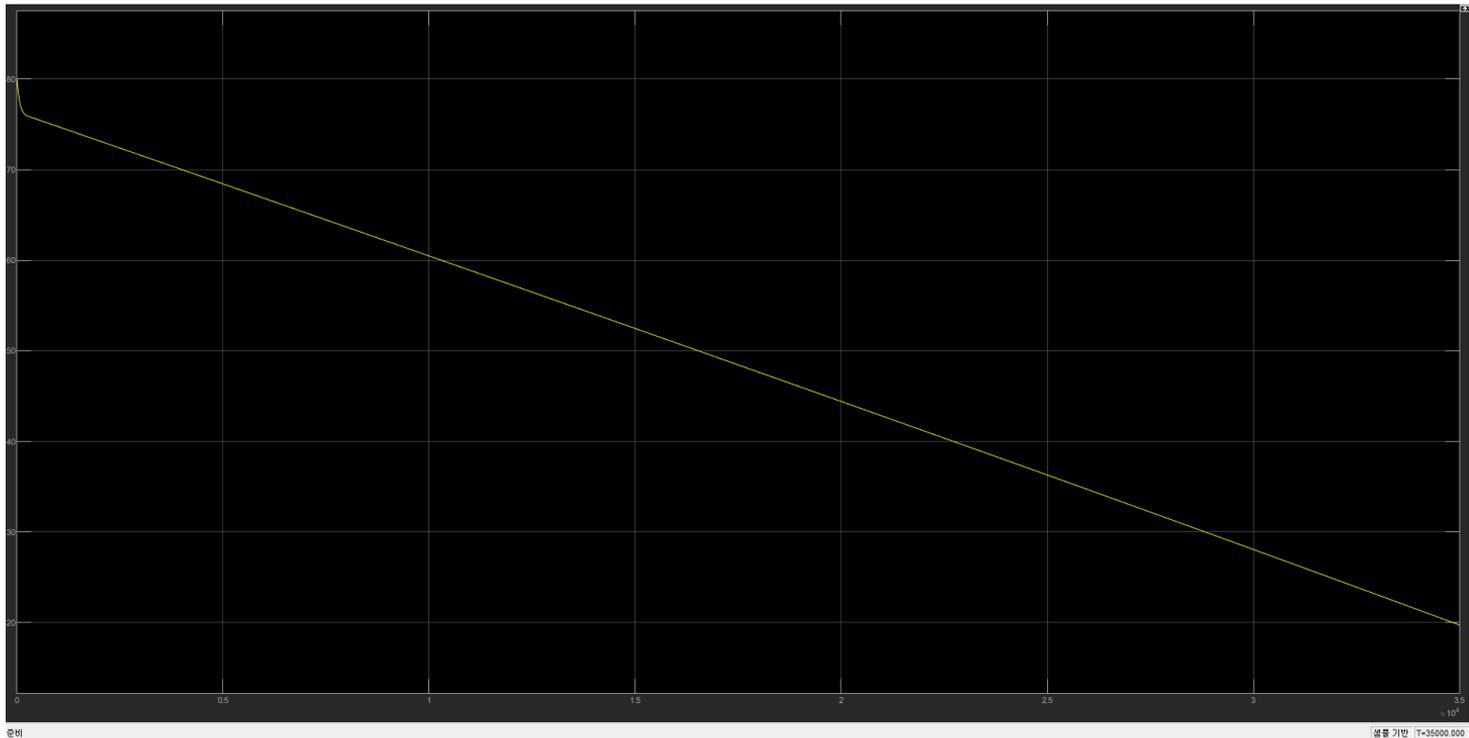
	A	B	C
1	0.0001	130	930.8
2	1250	130	930.8
3	1300	130	930.8
4	1400	120.7143	864.3143

Tq\_max - Excel



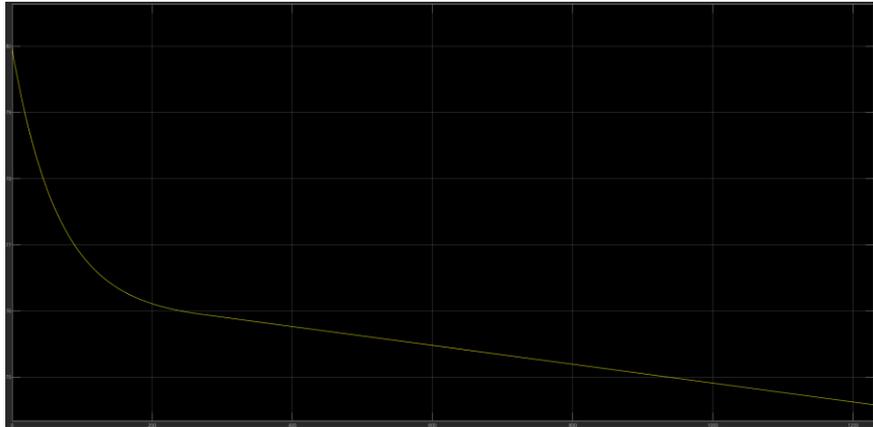
# 1 배터리 SOC 해석

[80%→20% SOC without charging  $\doteq$  35000 seconds]



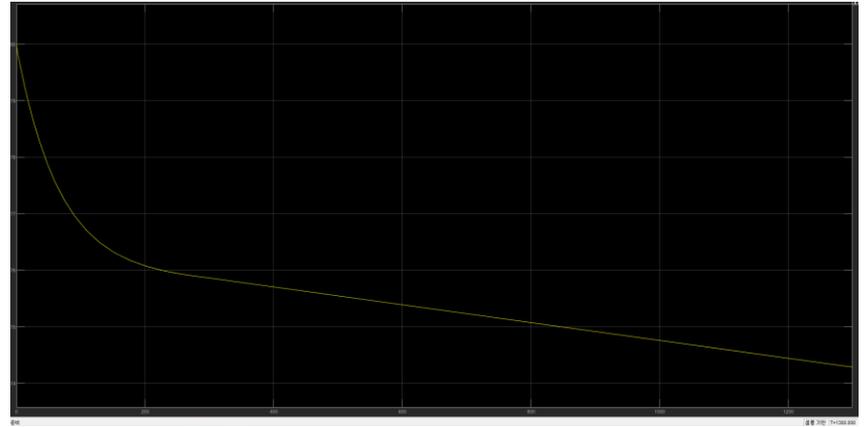
# 1 배터리 SOC 해석

[SOC **with** charging in 1300sec]



~75% at 936.1 (sec)  
~74.6% at 1216.7 (sec)

[SOC **without** charging in 1300sec]



~75% at 847.7 (sec)  
~74.6% at 1101.4 (sec)

# 1 배터리 SOC 해석

[80%→20% SOC **with** charging]

75% to 20% approx. 38582.5 seconds

80% to 20% approx. **10.977** Hours

658.643km

[80%→20% SOC **without** charging]

75% to 20% approx. 34883.75 seconds

80% to 20% approx. **9.92** Hours  
(9.925 Hours  $\doteq$  35000 seconds)

595.524km

At constant Velocity 60km/h

## 2 결과 & 결론

About **10.599%** Efficiency



### 3 고찰

1. mesh를 fine하게 짜지못해 정밀한 해석결과, 특히 접촉면적을 정확히 반영하지 못한다.
2. 타이어는 여러가지 재질이 layered된 제품으로 프로그램 내에 정확히 반영 불가하다.
3. 다양한 실험값이 없어, 비선형 모델의 해석법으로써 비교적 정확하지 않은 2차 Mooney-Rivlin 사용.
4. 타이어의 압력과 피에조 소자의 전압을 time domain상 연속적인 값으로 반영하지 않고 근사를 반복하면서 오차가 중첩된다.
5. 특정 차량모델에 대한 자세한 RPM vs Torque곡선과 SOC vs OCV/R in map을 얻지 못해 모델이 정확하게 반영되지 못한다.

## 참고문헌

1. Electrical4u.com
2. <https://kr.mathworks.com/matlabcentral/fileexchange/35735-charger-for-battery-48v-from-dc-source-32v-with-two-mode-cc-and-cv>
3. <https://www.engineersgarage.com/article/basics-li-ion-battery-charging-0>
4. [https://www.researchgate.net/post/How\\_does\\_a\\_CC-CV\\_charger\\_works\\_and\\_How\\_to\\_design\\_a\\_Buck\\_Converter\\_based\\_Battery\\_Charger](https://www.researchgate.net/post/How_does_a_CC-CV_charger_works_and_How_to_design_a_Buck_Converter_based_Battery_Charger)
5. <http://www.tft.ltu.lv/conference/proceedings2017/Papers/N043.pdf>
6. <https://www.comsol.com/blogs/piezoelectric-energy-harvester-increases-car-efficiency/>
7. <http://www.tft.ltu.lv/conference/proceedings2017/Papers/N043.pdf>
8. Evs Using Piezoelectric Phenomenon by Muhammad Kamran



**Q & A**