Dielectric Elastomer Generators: Influence of charging in actuation-like behaviour

P. Zanini, J. Rossiter, and M. Homer
Department of Engineering Mathematics, University of Bristol
Contact: plinio.zanini@bristol.ac.uk

DIELECTRIC ELASTOMERS?

- **Dielectric Elastomer (DE) transducers are lightweight, low cost, scalable and have high energy density** [1,2].
- DE transducers are a kind of electroactive polymer composite that consist of a stretchable polymer film coated with flexible electrodes. They are compliant variable capacitors.
- If charged electrostatically they can be used as actuators. They can also be exploited as generators due to capacitance change when deformed.
- When used as generators their behaviour is influenced by unwanted actuation. Being aware of this mechanism and how to minimise losses plays an important role in their use.

WHAT FOR?

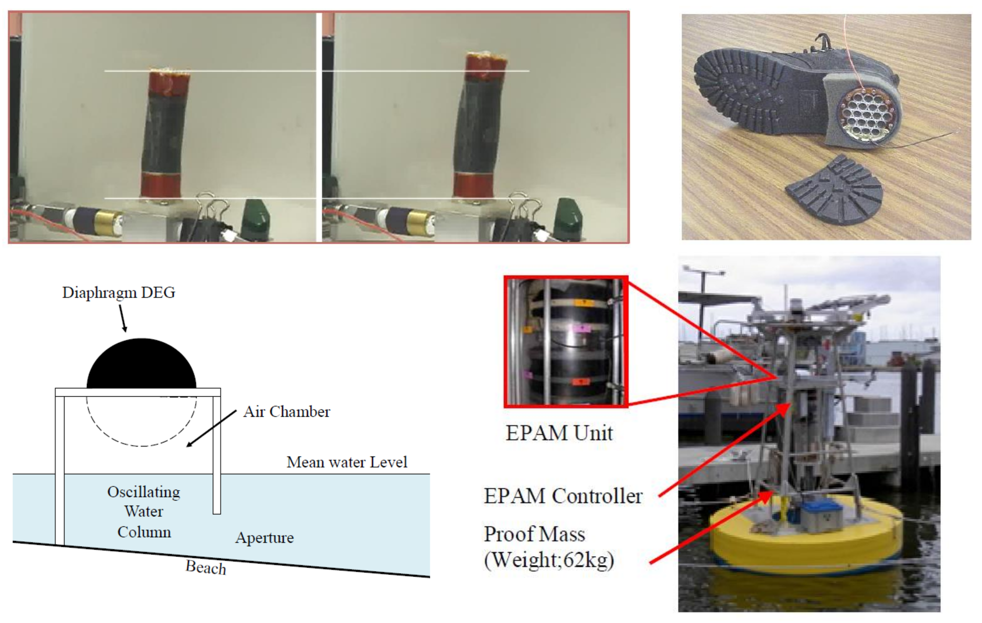

Figure 3: Applications of DEG: Polymeric combustion engine and heel strike energy harvester [1]; Wave energy using diaphragm [2] and buoy [3]

SIMULATION MODEL

- We adopted a model provided in literature for mechanical behaviour [6] in pure-shear conditions:

$$m\ddot{x} = F_x - d_v\dot{x} - \frac{B}{x}\left(G\frac{\lambda_x^{\,4}-1}{\lambda_x^{\,2}} + \sigma_z\right)$$

- The model was implemented using Simulink. SimElectronics elements allowed us to reproduce the electrical circuit in a SPICE-like environment.
- DEG sample considered had initial area of 0.02m² and was 0.1mm thick, with initial capacitance of 8.3nF
- Material parameters were taken from an approximation of the shear modulus of 3M VHB 4910 from Ogden model parameters[6].

CONCLUSIONS

- We have shown that Dielectric elastomer Generators exhibit and **actuator-like behaviour** and demonstrate that it can affect the energy harvesting cycle outcome.
- We showed that, for an specific case, with **energy output of 198mJ,** we could **increase the energy harvested from 7mJ to 37mJ** through a different mode of charging.
- Electrical energy dissipation corresponds to 90% of the 30mJ energy difference. Viscous losses are responsible for the remaining 10% difference.

HOW DOES IT WORK?

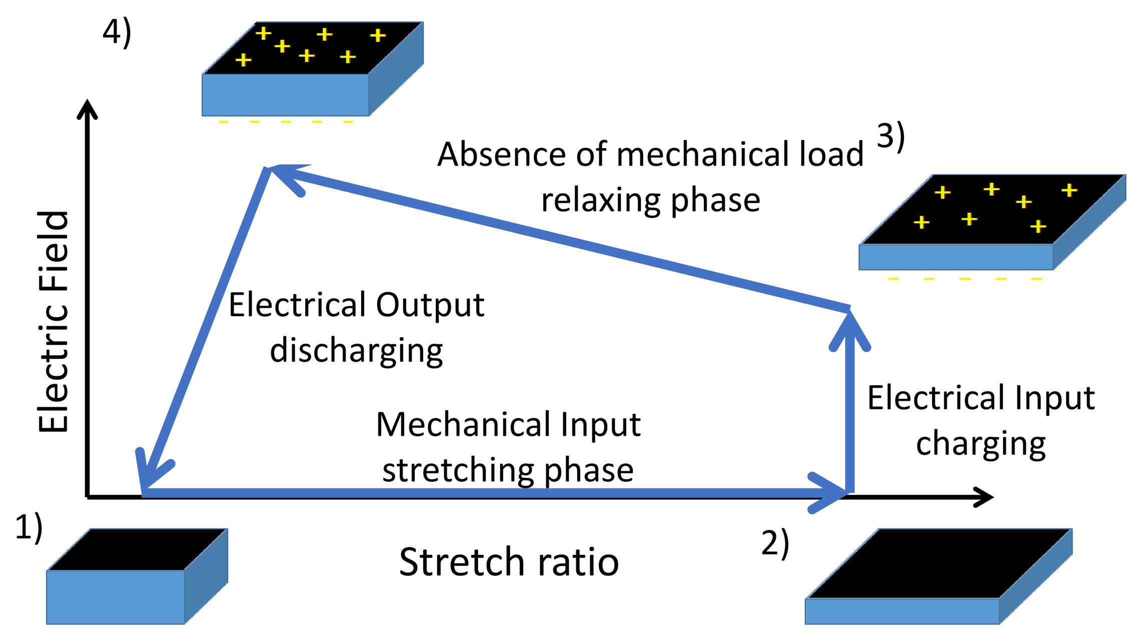

Figure 1: Phases and processes of the DEG energy harvesting cycle

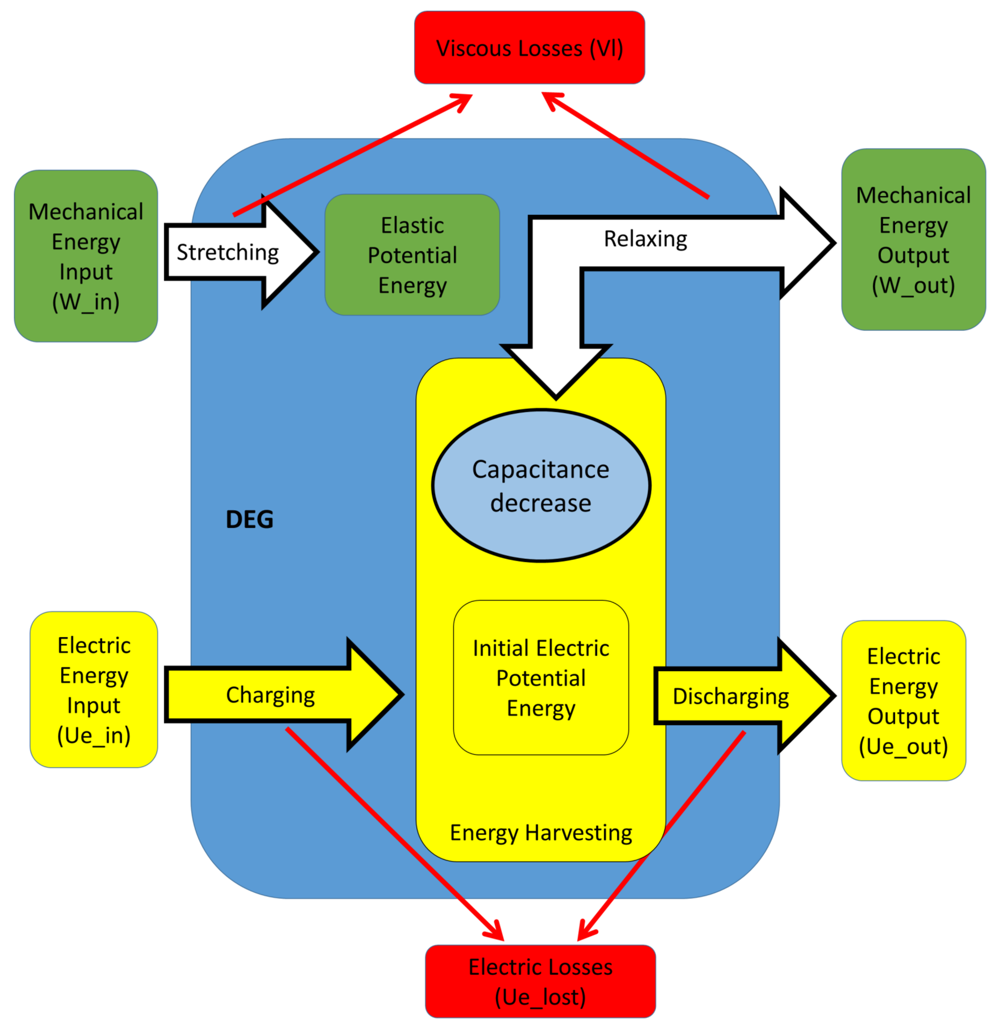

Figure 2: Energy flux through the DEG cycle

STUDY GOALS

- Present dielectric elastomers and their possible uses as energy harvesters.
- Report the phenomenon of **charging-induced actuation in Dielectric Elastomer Generators** (DEG) and understand its impact.

METHOD

- Through simulation, we **compared two different modes of operating the charging phase** (2 → 3) in the DEG cycle (Modes A and B, see Figure 4) for a DEG stretched through pure-shear conditions (see Figure 5). Voltage is controlled through a controlled voltage source and switches S1 and S2 (Figure 6).
- **Mode A:** Charging exposes the DEG to a **high voltage that takes it to state 2.5'**. Voltage rise induces actuation in the DEG, taking it to the equilibrium state 3. Capacitance increase while in open-circuit conditions lower the voltage.
- **Mode B:** Charging exposes the DEG to the **same voltage level of stage 3** in Mode A, which takes it to state 2.5''. Charging proceeds under constant voltage while the DEG deforms due to actuation and accommodate the new charges, matching equilibrium state 3 (same voltage and stretch ratio).

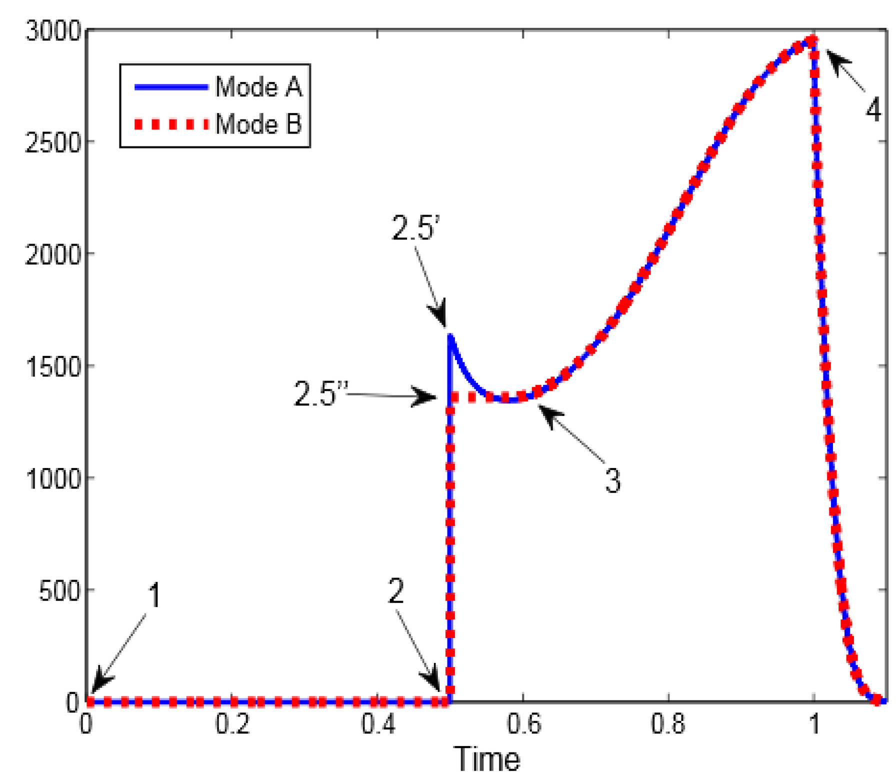

Figure 4: Voltage of the DEG as a function of time [4].

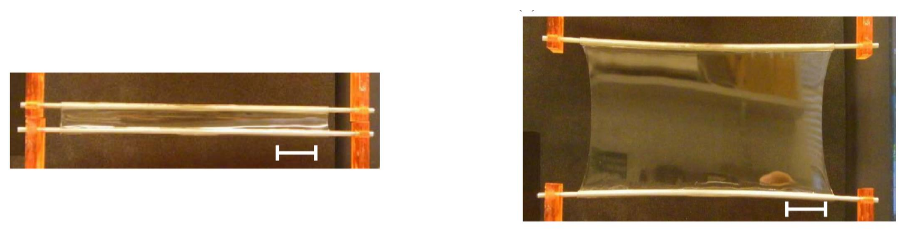

Figure 5: Membrane stretched under pure-shear conditions [5].

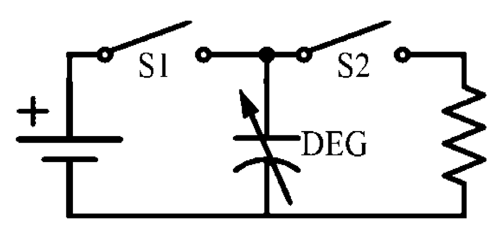

Figure 6: Circuit used in the simulations [4].

RESULTS

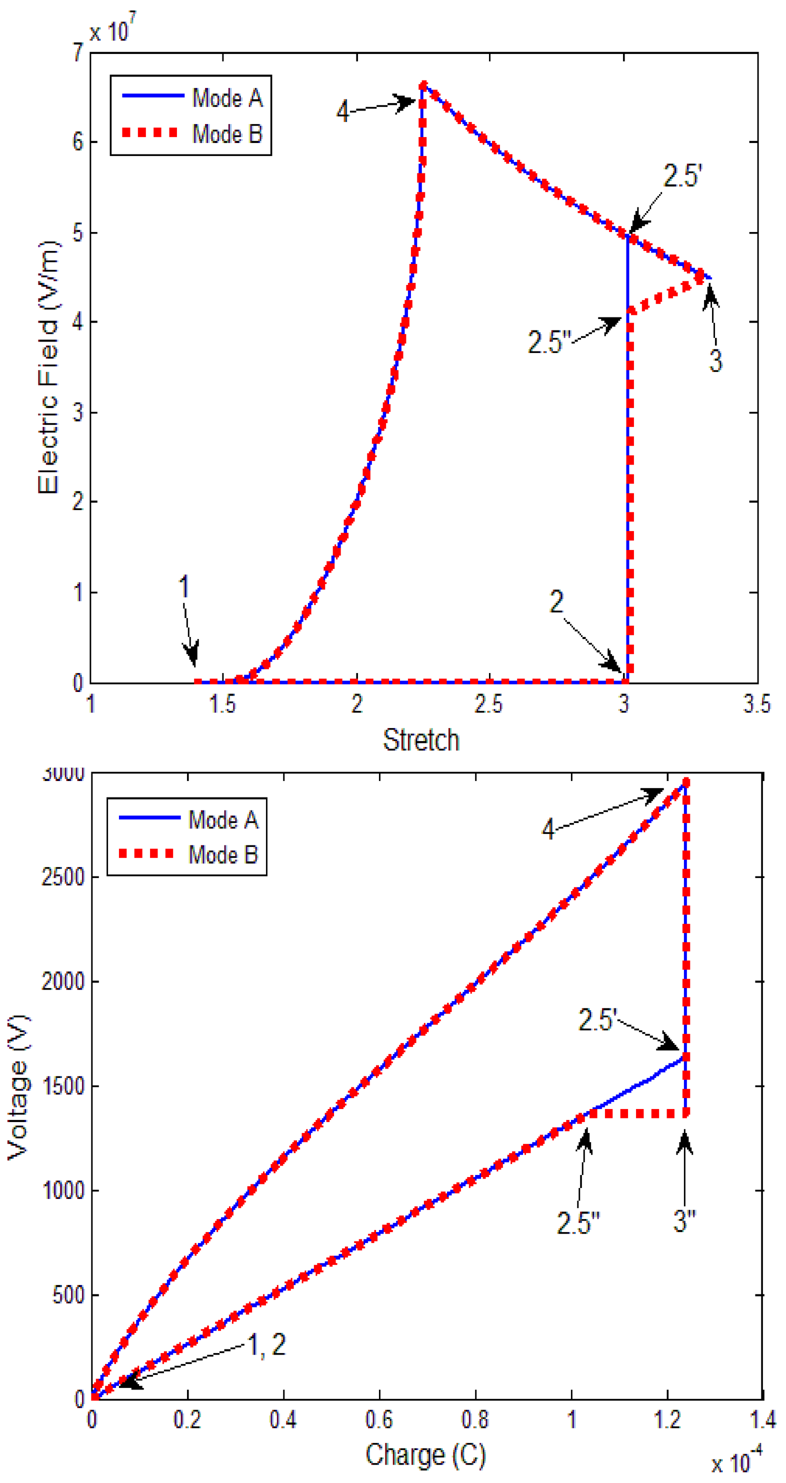

Figure 7: Electric Field as a function of Stretch Ratio (top) and Voltage as a function of Charge (bottom) [4].

TABLE I. Electrical energy balance during process 2-3 comparing charging modes A and B.

		Mode A	Mode B
a	Electric Energy Input at 2.5	0.190 J	0.131 J
b	Electric Energy Input 2.5-3	0 J	0.029 J
c	Total Electric Energy input 2-3 (a+b)	0.190 J	0.160 J
d	Electric Energy Dissipated 2-3	(0.088) J	(0.061) J
e	Actuation Energy (electrical to mechanical conversion) 2-3	(0.017) J	(0.014) J
f	Electric Energy Stored at 3 (c+d+e)	0.085 J	0.085 J

TABLE II. Mechanical energy balance during process 2-3 comparing charging modes A and B.

		Mode A	Mode B
g	External Mechanical Work 2-3	0.138 J	0.130J
h	Mechanical Energy Damped 2-3	(0.014) J	(0.011) J
i	Actuation Energy (electrical to mechanical conversion) 2-3	0.017 J	0.014 J
j	Strain Energy change 2-3 (g+h+i)	0.141 J	0.133 J

REFERENCES
[1] Kornbluh, R. D., et al: "From boots to buoys: Promises and challenges of dielectric elastomer energy harvesting" Spie-Int Soc Optical Engineering, Bellingham(2011).
[2] Vertechy R., et al: "In-tank tests of a dielectric elastomer generator for wave energy harvesting". Proc. SPIE 9056, EAPAD 2014, 90561G (2014).
[3] Chiba, S., et al:" Novel Electric Generator Using Electroactive Polymer Artificial Muscle (EPAM)". Proc. WHEC 2010: Parallel Sessions Book 3: Hydrogen Production Technologies - Part 2 / Detlef Stolten, Thomas Grube (Ed.) Forschungszentrum Jülich GmbH, Zentralbibliothek, Verlag (2010).
[4] Zanini, P., et al.: "Modelling the effect of actuator-like behavior in dielectric elastomer generators", Appl. Phys. Lett., 107, 153906 (2015).
[5] He, T., et al.: "Dielectric elastomer membranes undergoing inhomogeneous deformation", J. Appl. Phys. 106, 083522 (2009)
[6] Graf, C. , et al.: "Simulation model for electro active polymer generators", IEEE Int. C. Sol. Diel. (2010).

University of Bristol
CNPq Conselho Nacional de Desenvolvimento Científico e Tecnológico
CIÊNCIA SEM FRONTEIRAS