Saft SOLUTIONS FOR FULL GEO ELECTRIC PROPULSION

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ABSTRACT

Today, the full electric propulsion is becoming more commonly used on board geostationary satellites for the launch up to the Electrical Orbit Raising (EOR) and all on-orbit manoeuvres.
This electrical propulsion induces additional cycles for the battery that may result in higher ageing.
The Electrical Orbit Raising (EOR) is currently simulated by two additional GEO seasons up to 80%DoD while the Plasmic Propulsion System (PPS) cycles are carried out, at least 162 cycles up to 24%DoD or 198 cycles up to 20%DoD per solstice season and at least 52 cycles up to 15%DoD or 64 cycles up to 10%DoD per eclipse season for 15 years.
The need for an appropriate demonstration by life-test was anticipated and addressed in collaboration with the primes and the agencies, in the frame of ARTES 3-4 contract with ESA for the VES180SA cell & CNES contract for the VES16 cell.
The article will present the whole cycling results available, and will provide afterwards the correlation status of Saft Li-ion Model (SLIM) with the experimental data acquired.

Keywords: **DOD**: Depth of Discharge; **OCV**: Open Circuit Voltage; **EOCV**: End Of Charge Voltage; **EODV**: End Of Discharge Voltage; **EOR**: Electrical Orbit Raising; **GEO**: Geosynchronous Orbit; **IR**: Internal Resistance; **PPS**: Plasmic Propulsion System; **SG**: Strain Gauge; **SLIM**: Saft Li-Ion Model; **SoC**: State of Charge.

1. VES180SA LI-ION CELL WITH & WITHOUT PPS GEO LIFE-TEST RESULTS

This chapter focuses on the analysis of the life-test results performed on VES180SA lithium-ion cells with and without PPS in semi-accelerated mode covering different mission profiles proposed by primes, as described in Tab. 1. The life time test performed without PPS is used as reference test in order to evaluate the impact of the Electrical Orbit Raising (EOR) and all on-orbit manoeuvres (PPS) on the cell ageing.

Test Ref.	Test conditions	Nb Cells Tested	Achieved Seasons	Test Status
NDTF17 Semi-Acceler.	Semi-Accelerated GEO cycling at 75%DoD @15°C EOCV = 4.075V without PPS (Reference Test)	1	16	On-going
	Semi-Accelerated GEO cycling at 75%DoD @15°C Two initial seasons without PPS EOCV = 4.075V with PPS (10%DoD in equinox & 20%DoD in solstice)	2	16	On-going
NDTF18 Semi-Acceler.	Semi-Accelerated GEO cycling at 75%DoD @20°C EOCV = 4.075V without PPS (Reference Test)	1	18	On-going
	Semi-Accelerated GEO cycling at 75%DoD @20°C Two initial seasons without PPS EOCV = 4.075V with PPS (15%DoD in equinox & from 19% to 24%DoD in solstice)	2	18	On-going

Table 1: VES180SA Li-ion cells On-Going GEO with & without PPS Life-Tests Program

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1.1 NDTF17 & 18 Test Set-Ups

The test set-ups applied to the NDTF 17 and 18 lifetime tests are similar, except for the base plate regulation temperature which varies respectively from 15 to 20 °C.

For each lifetime test, three VES180SA cells were encapsulated "head down" in 3P cell-package and instrumented with two circumferential strain-gages, one thermocouple and one voltage telemetry in order to measure the PPS effect on the evolution of the temperature, the EOD voltage and the cell swelling. Then, they have undergone the specified mechanical and vacuum environmental tests without presenting leakage mark and abnormal degradations of their electrical performances.

Before starting the lifetime tests, the two cell-packages were assembled with a CHO- THERM layer on thermally regulated baseplate and insulated from ambient temperature by insulating box, as presented in the Fig. 1, 2 and 3.

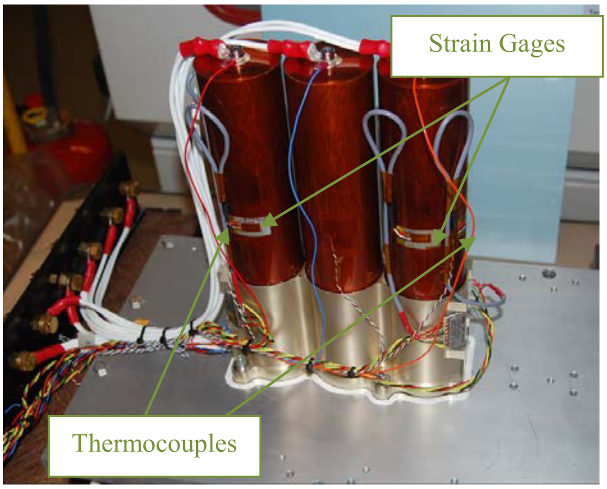

Figure 1. Cell-Package instrumented and mounted on baseplate

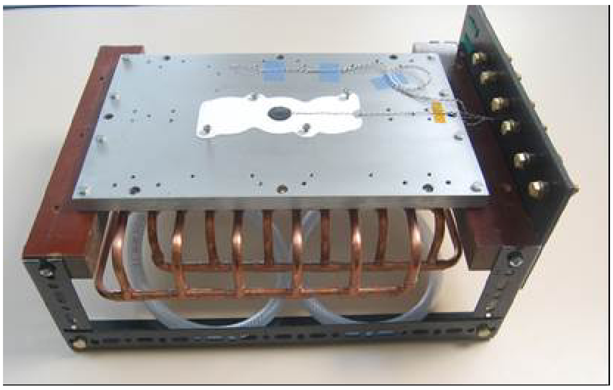

Figure 2. Regulated Baseplate with thermocouple and CHO-THERM under Cell-Package

Figure 3. Regulated Baseplate with Insulating box

1.2 NDTF17 Lifetime Test Results

- In cycling, we have not observed significant impact of PPS on EoD voltage at the longest eclipse (cycle 23), as presented in Fig. 4 and 5.

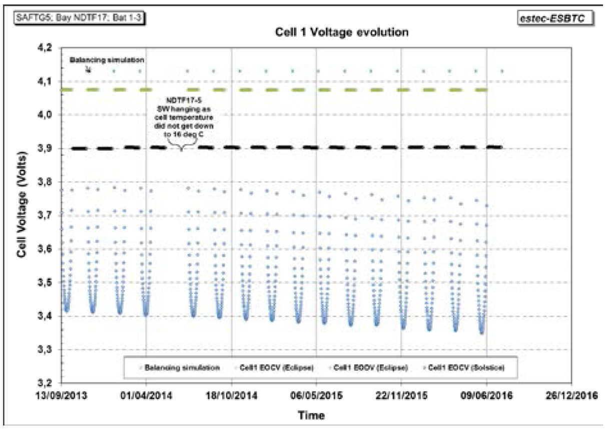

Figure 4. EoC/EoD Voltage variation in GEO Cycling without PPS

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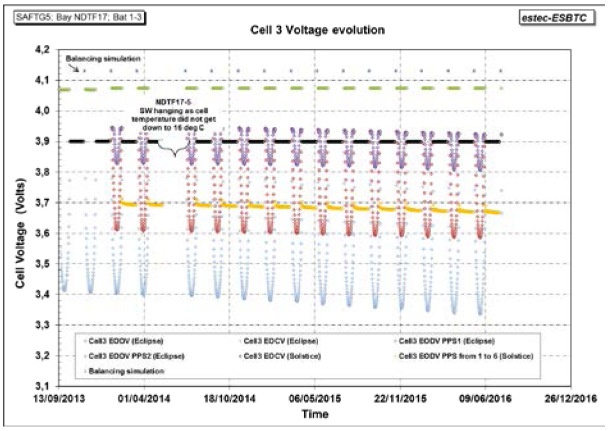

Figure 5. EoC/EoD Voltage variation in GEO Cycling with PPS

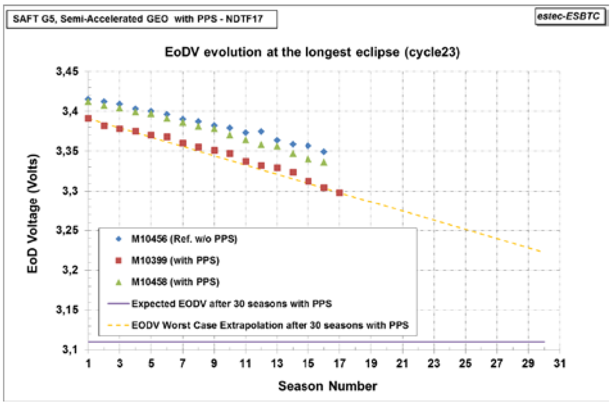

Figure 6. EoD Voltage at cycle 23 evolution vs. season

EOD voltage variation slopes are respectively between -5.8 & -5.1 mV per season for M10399 & M10458 cells cycled with PPS compared to -4.4 mV per season for M10456 cell cycled without PPS. These slopes should permit to maintain EOD Cell Voltage over the expected value after 30 seasons with PPS (i.e. ≥ 3.11Volts), as presented in Fig. 6.

-Also during cycling, no difference was identified on the evolution of the cell swelling at the end of charging (similar circumferential strains measured around 1000 ppm at the longest eclipse with or without PPS) and on the cell temperature increase at the end of discharge (similar temperature measured around 22°C at the longest eclipse with or without PPS), refer respectively to Fig.7 and 8, then Fig.9 and 10.

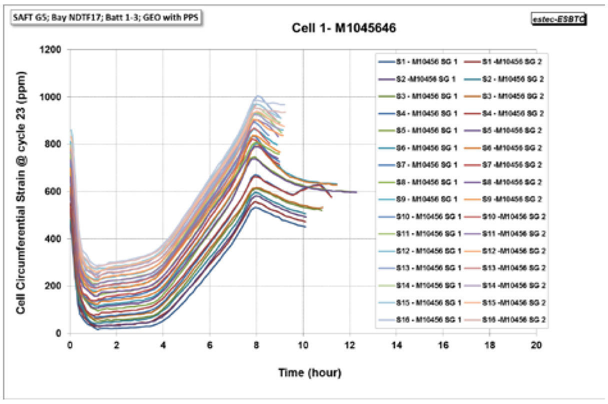

Figure 7. Cell 1 Circumferential strains evolution at cycle 23 without PPS vs. season

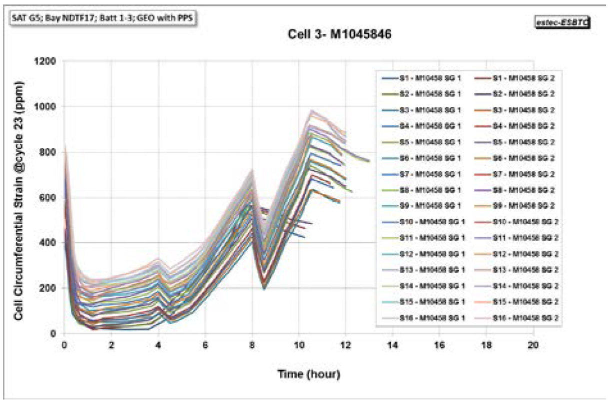

Figure 8. Cell 3 Circumferential strains evolution at cycle 23 with PPS vs. season

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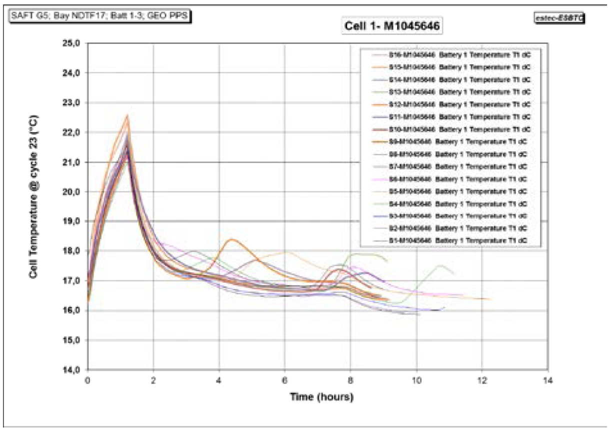

Figure 9. Cell 1 Temperature evolution at cycle 23 without PPS vs. season

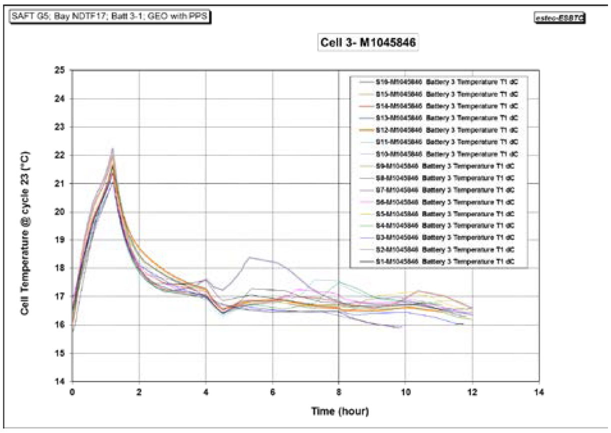

Figure 10. Cell 3 Temperature evolution at cycle 23 with PPS vs. season

- The evolution of the cell characteristics, such energy, IR20%DoD and IR60%DoD is measured through a check-up sequence, involving a residual discharge and a reference test performed at EOCV=4.1V @15°C every two seasons. This reference test is based on charge up to 4.1V, then discharge down to 2.7V under C/2 discharge rate @15°C with pulses 1.5C-30seconds at 20% and 60%DoD.

After 16 GEO seasons, no significant impact of PPS is visible on the energy variation slopes.

That should permit to maintain energy loss under the expected value after 30 seasons with PPS (i.e. ≤10.5%), as presented in Fig.12. The changes noticeable on the energy evolution are mainly induced by EoD temperature variation, as presented in Fig.11.

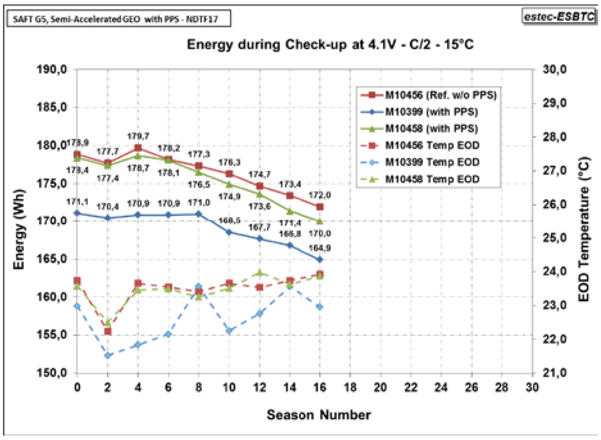

Figure 11. Energy & Temperature evolution in GEO cycling with & without PPS

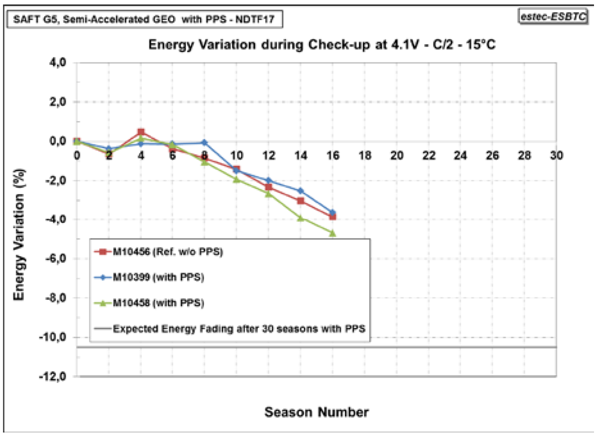

Figure 12. Energy variation in GEO cycling with & without PPS

Also, no significant difference was identified on the evolution of Internal Resistance at 20% & 60%DoD

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after 16 GEO seasons with or without PPS, as presented respectively in Fig.13 and 14.

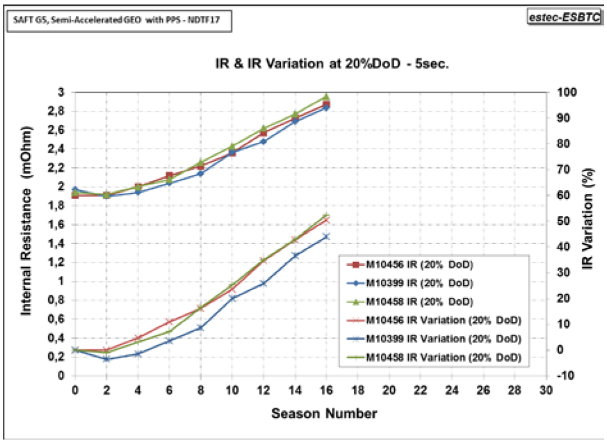

Figure 13. IR20%DoD variation with & without PPS

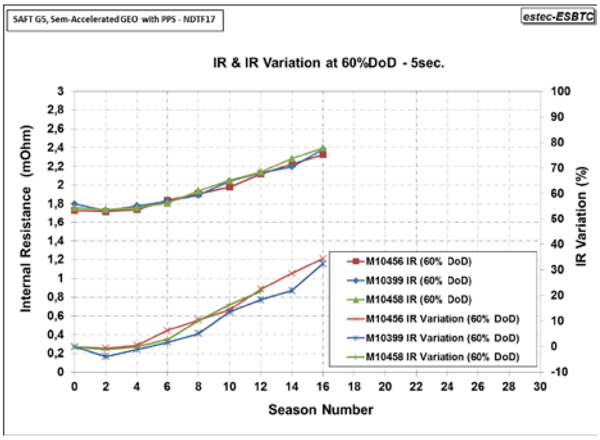

Figure 14. IR60%DoD variation with & without PPS

1.3 NDTF18 Lifetime Test Results

- In cycling, we have not observed significant impact of PPS on EoD voltage at the longest eclipse (cycle 23), as presented in Fig. 15 and 16.

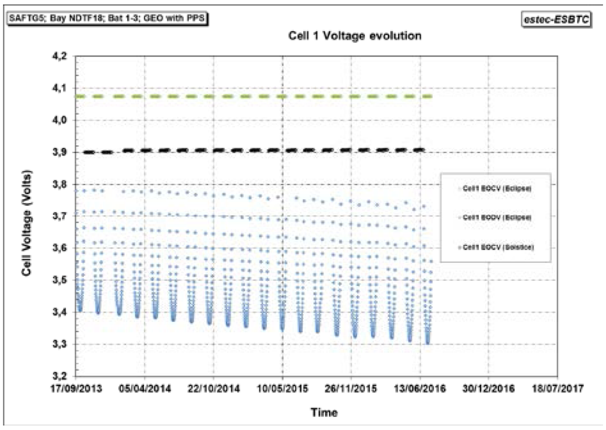

Figure 15. EoC/EoD Voltage variation in GEO Cycling without PPS

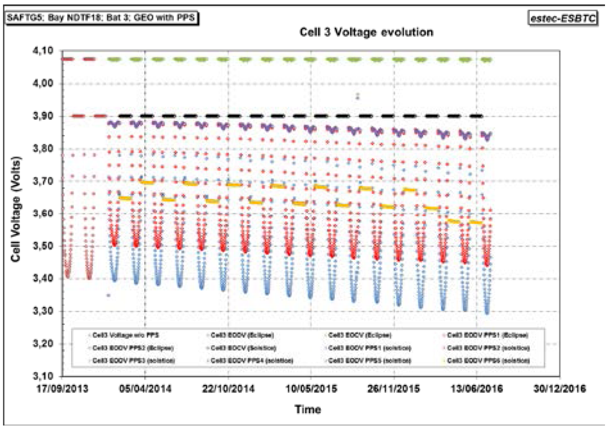

Figure 16. EoC/EoD Voltage variation in GEO Cycling with PPS

EOD voltage variation slopes are respectively between -5.2 & -5.9 mV per season for M10459 & M10377 cells cycled with PPS compared to -5.3 mV per season for M10376 cell cycled without PPS.
These slopes should permit to maintain EOD Cell Voltage over the expected value after 30 seasons with PPS (i.e. ≥ 3.14Volts), as presented in Fig. 17.

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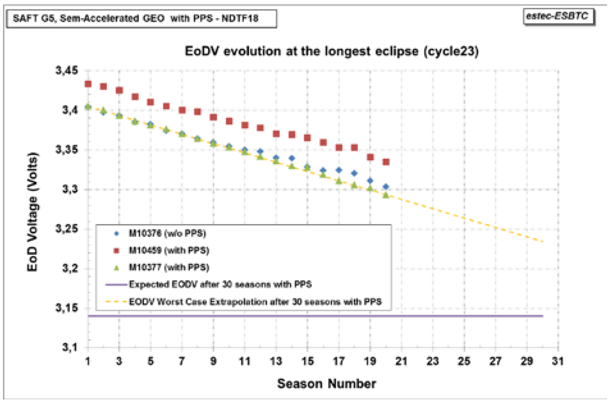

Figure 17. EoD Voltage at cycle 23 evolution vs. season

-Also during cycling, no significant difference was identified on the evolution of the cell swelling at the end of charging and on the cell temperature at the end of discharge, respectively about 100 ppm increase and 1°C decrease were measured in GEO cycling with PPS at the longest eclipse, refer respectively to Fig.18 and 19, then Fig.20 and 21.

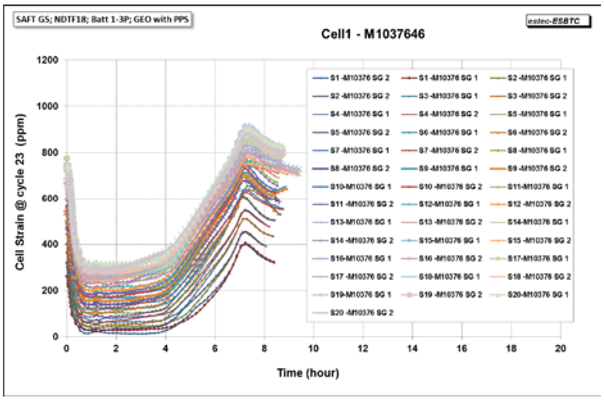

Figure 18. Cell 1 Circumferential strains evolution at cycle 23 without PPS vs. season

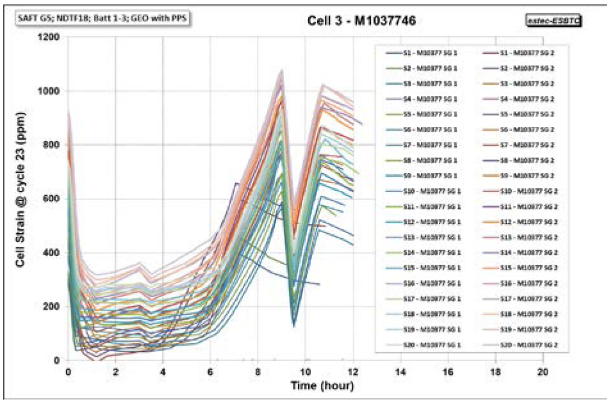

Figure19. Cell 3 Circumferential strains evolution at cycle 23 with PPS vs. season

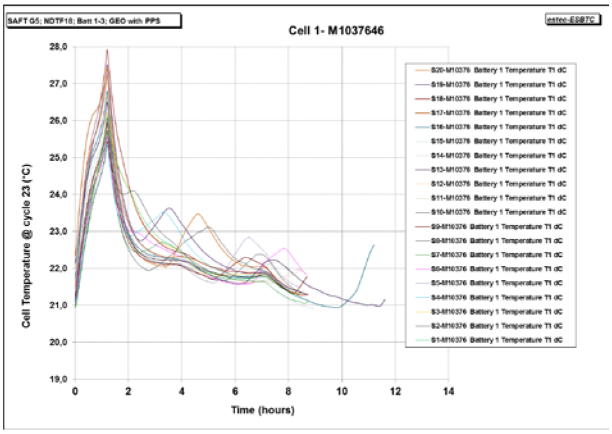

Figure 20. Cell 1 Temperature evolution at cycle 23 without PPS vs. season

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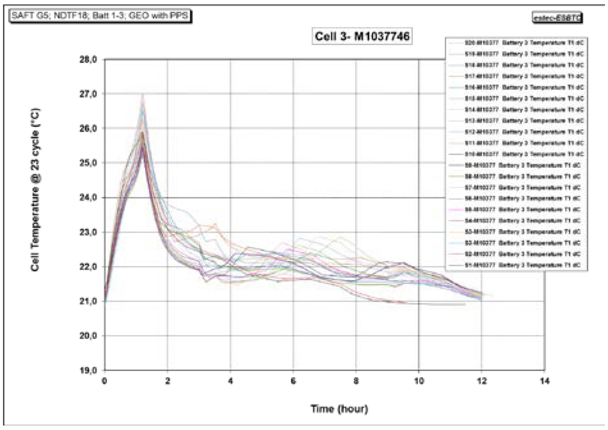

Figure 21. Cell 3 Temperature evolution at cycle 23 with PPS vs. season

- The evolution of the cell characteristics, such energy, IR20%DoD and IR60%DoD is measured every two seasons through a check-up sequence, involving a residual discharge and a reference test performed at EOCV=4.1V @20°C.

This reference test is based on charge up to 4.1V, then discharge down to 2.7V under C/2 discharge rate @20°C with pulses 1.5C-30seconds at 20% and 60%DoD.

After 18 GEO seasons, no significant impact of PPS is visible on the energy variation slopes. That should permit to maintain energy loss under the expected value after 30 seasons with PPS (i.e. ≤11.2%), as presented in Fig. 23.

The changes noticeable on the energy evolution are mainly induced by EoD temperature variation, as presented in Fig.22.

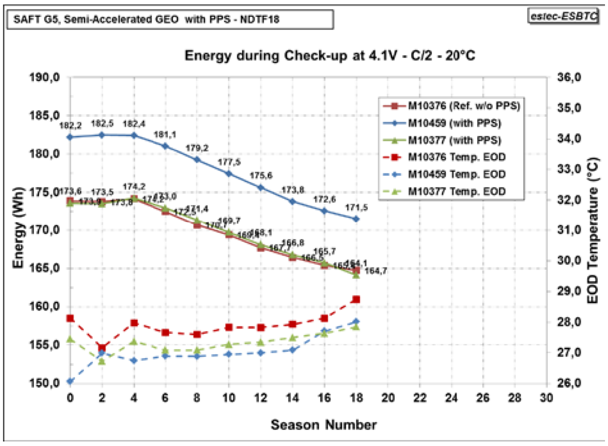

Figure 22. Energy & Temperature evolution in GEO cycling with & without PPS

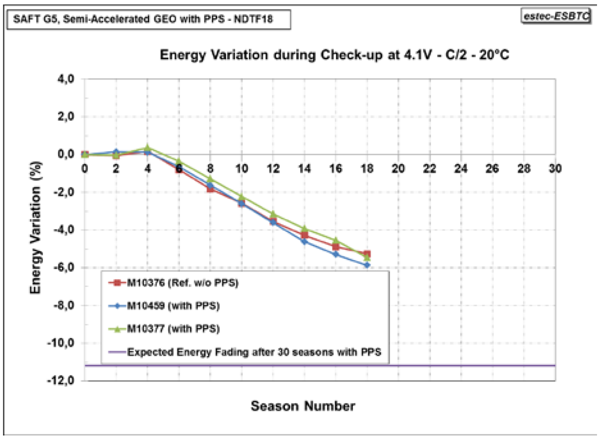

Figure 23. Energy variation in GEO cycling with & without PPS

Also, no significant difference was identified on the evolution of Internal Resistance at 20% & 60%DoD after 18 GEO seasons with or without PPS, as presented respectively in Fig.24 and 25.

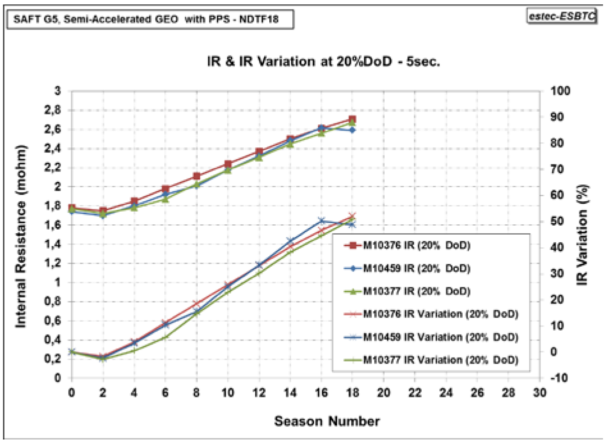

Figure 24. IR20%DoD variation in GEO cycling with & without PPS

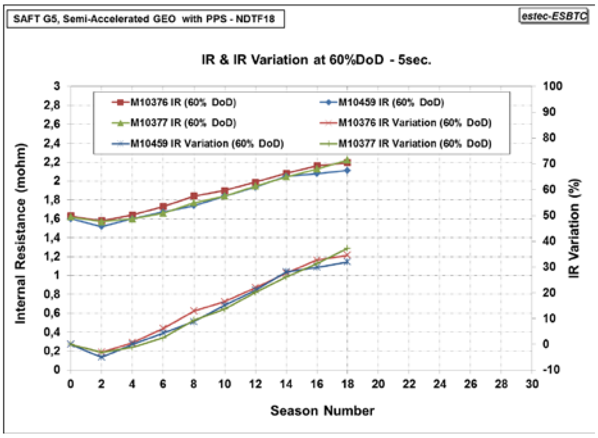

Figure 25. IR60%DoD variation in GEO cycling with & without PPS

1.4 Conclusion

The effect of PPS discharge on those GEO cycling tests @ 4.075V are negligible in term of energy loss, EoDV drop and internal resistance increase, which confirm the excellent ability of VES180 cell to sustain GEO PPS missions.
As of today after respectively 16 and 18 seasons, the expended EoL PPS trends are in line with SLIM predictions on the two experimented PPS profiles, including some margin as the results are better than prediction so far.

2. VES16 LI-ION CELL WITH & WITHOUT PPS GEO LIFE-TEST RESULTS

This chapter focuses on the analysis of the life-test results performed on VES16 lithium-ion cells with and without PPS in semi-accelerated mode, as described in Tab. 2. The life time test performed without PPS is used as reference test in order to evaluate the impact of the Electrical Orbit Raising (EOR) and all on-orbit manoeuvres (PPS) on the cell ageing.

Test Ref.	Tests Conditions	Nb Cells Tested	Achieved Seasons	Test Status
G10a Semi-Acceler.	80%DoD per cell duration per GEO Pofile @20° EOCV = 4.05 V No PPS	1	14 seasons	On-going
G10b Semi-Acceler.	Equinox periods: 2 GEO cycles per day at 80%DoD with 2 PPS cycles at 10%DoD @20° EOCV = 4.05 V Solstice periods: 6 PPS cycles per day at 20%DoD	2	14 seasons	On-going

Table 2: VES16 Li-ion cells On-Going GEO with & without PPS Life-Tests Program

2.1 G10a and G10b Test Set-Ups

The test set-ups applied to the G10a and G10b lifetime tests are similar.
All VES16 cells were instrumented with one thermocouple and one voltage telemetry in order to measure the PPS effect on the evolution of the temperature and the EOD voltage.
Before starting the lifetime tests, all VES16 cells were located in a ventilated thermal chamber set at 20°C.

2.2 G10a and G10b Lifetime Test Results

- In cycling, we have not observed significant impact of PPS on EoD voltage at the longest eclipse (cycle 23), as presented in Fig. 26 and 27.

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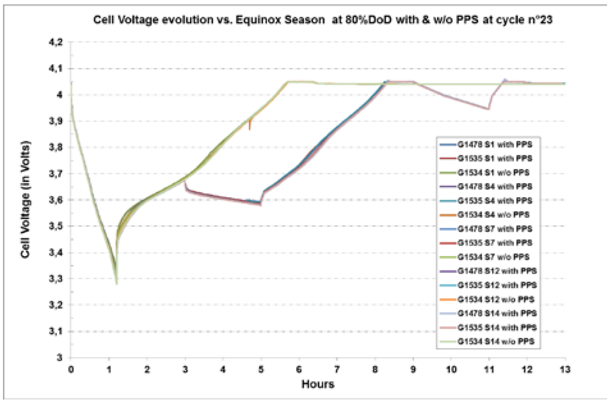

Figure 26. EoC/EoD Voltage variation in GEO Cycling with & without PPS (Equinox period)

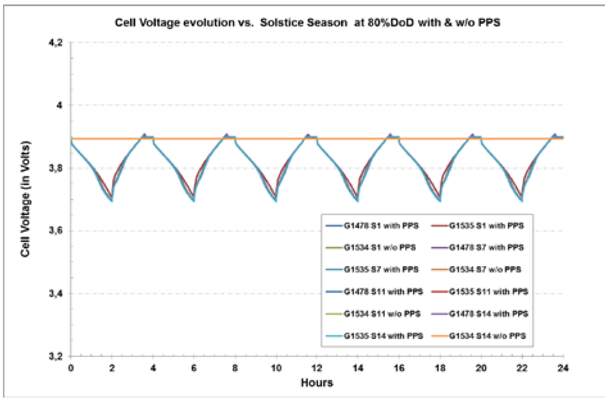

Figure 27. EoC/EoD Voltage variation in GEO Cycling with & without PPS (Solstice period)

EOD voltage variation slopes are all same at -3.0mV per season.

These slopes should permit to maintain EOD Cell Voltage over the expected value after 30 seasons with PPS (i.e. ≥ 3.22Volts), as presented in Fig. 28.

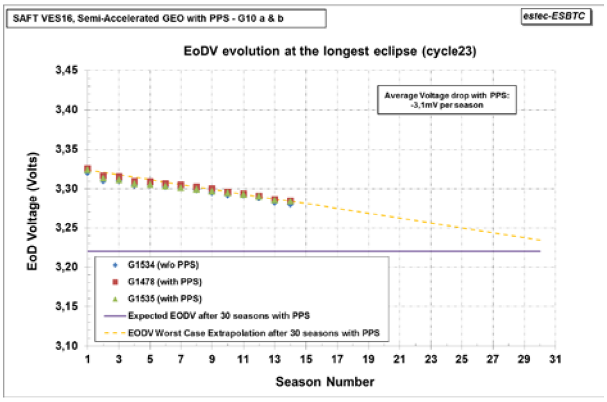

Figure 28. EoD Voltage at cycle 23 evolution vs. season

-Also during cycling, no difference was identified on the evolution of the cell temperature increase at the end of discharge (similar temperature measured around 24°C at the longest eclipse with or without PPS), refer to Fig.29.

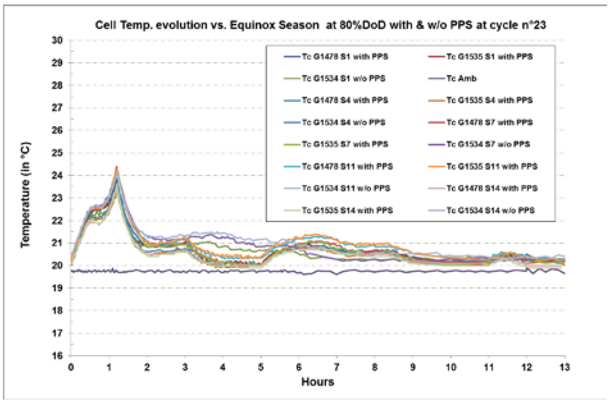

Figure 29. Cell Temperature evolution at cycle 23 with & without PPS vs. season

- The evolution of the cell characteristics, such energy, IR20%DoD and IR60%DoD is measured every two seasons through a check-up sequence, involving a residual discharge and a reference test performed at EOCV=4.1V @20°C.

This reference test is based on charge up to 4.1V, then discharge down to 2.7V under C/2 discharge rate @20°C with pulses 1.5C-30seconds at 20% and

60%DoD.
After 14 GEO seasons, no significant impact of PPS is visible on the energy variation slopes. That should permit to maintain energy loss under the expected value after 30 seasons with PPS (i.e. ≤ 9.9%), as presented in Fig. 30.

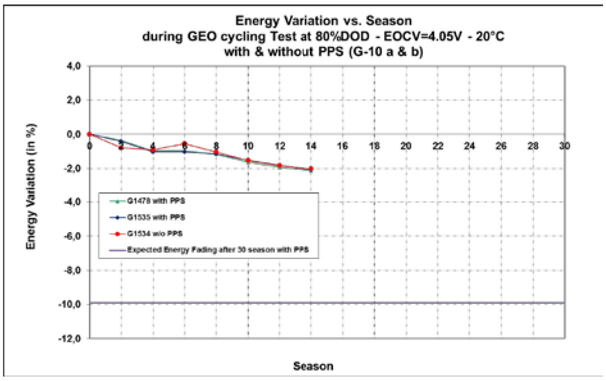

Figure 30. Energy variation in GEO Cycling with & without PPS

Also, no significant difference was identified on the evolution of Internal Resistance at 20% & 60%DoD after 14 GEO seasons with or without PPS, as presented respectively in Fig.31 and 32.

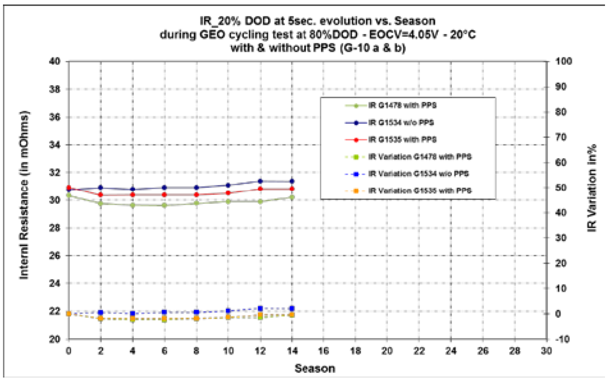

Figure 31. IR20%DoD variation in GEO cycling with & without PPS

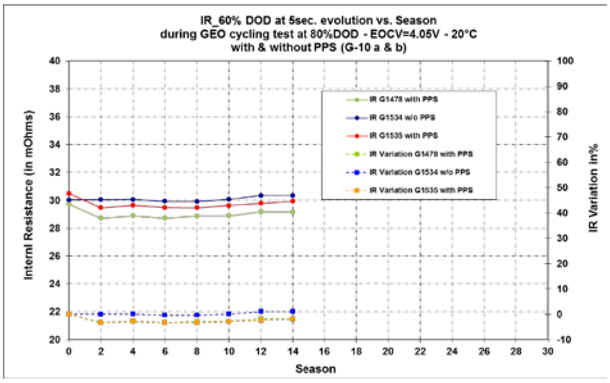

Figure 32. IR60%DoD variation in GEO cycling with & without PPS

2.3 Conclusion

The effect of PPS discharge on those GEO cycling tests @ 4.05V are negligible in term of energy loss, EoDV drop and internal resistance increase, which confirm the excellent ability of VES16 cell to sustain GEO PPS missions.
As of today after respectively 14 seasons, the expended EoL PPS trends are in perfectly line with SLIM predictions.

3. REFERENCES

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3. Defer, M., Du Peyrat, D., Prevot, D. & Borthomieu, Y. Qualification of High Specific Energy Li-Ion Cell VES180SA, 8th ESPC 2008 - Article S13-2 / Session 13.