MURRAYLINK – IGBT ECONOMIC ANALYSIS

Approach and Preliminary Results

12 October 2022

Oakley Greenwood

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Agenda

Agenda is:

- Outline our approach to undertaking this assignment
- Discuss our high-level, preliminary results.
- Clearly outline the factors driving future uncertainty around the timing of CAPEX.

Approach

Our overarching approach has been to:

- Undertake a “with” and “without” ML wholesale market model run using PLEXOS
  - Provides half-hourly dispatch costs under both runs, by region
  - Relied on ISP Step Change scenario input assumptions and generation capacity build
- Aggregated each of the regional half hourly dispatch cost outcomes under each run into an Excel sheet, and then determined the difference in each half hour, for inclusion in NPV model
- NPV model:
  - Randomly combines a failure curve with a CAPEX solution to create a “scenario”; 40 scenarios run (multiple times)
    - 15 potential failure curves for IGBTs in the model
      - 5*BaU (meaning it has a 33% probability of occurence);
      - 10% / 20% / 33% pa increase in failures
      - BathTub curves:
        - » BAU+ y10 10%/20% etc
        - » BAU+ y15 10%/20% etc
    - 3 capex solutions modelled:
      - GEN2 IGBT to GEN 3 IGBT (per phase) - ~$20.5m (raw costs plus 15% overhead)
      - Upgrade one converter station to VSC MMC - ~$42.2m (raw costs plus 15% overhead)
      - Upgrade both converter stations to VSC MMC - ~82.5m (raw costs plus 15% overhead)
    - All capex costs and possible failure rates sourced from external consultants engaged by APA (Amplitude)

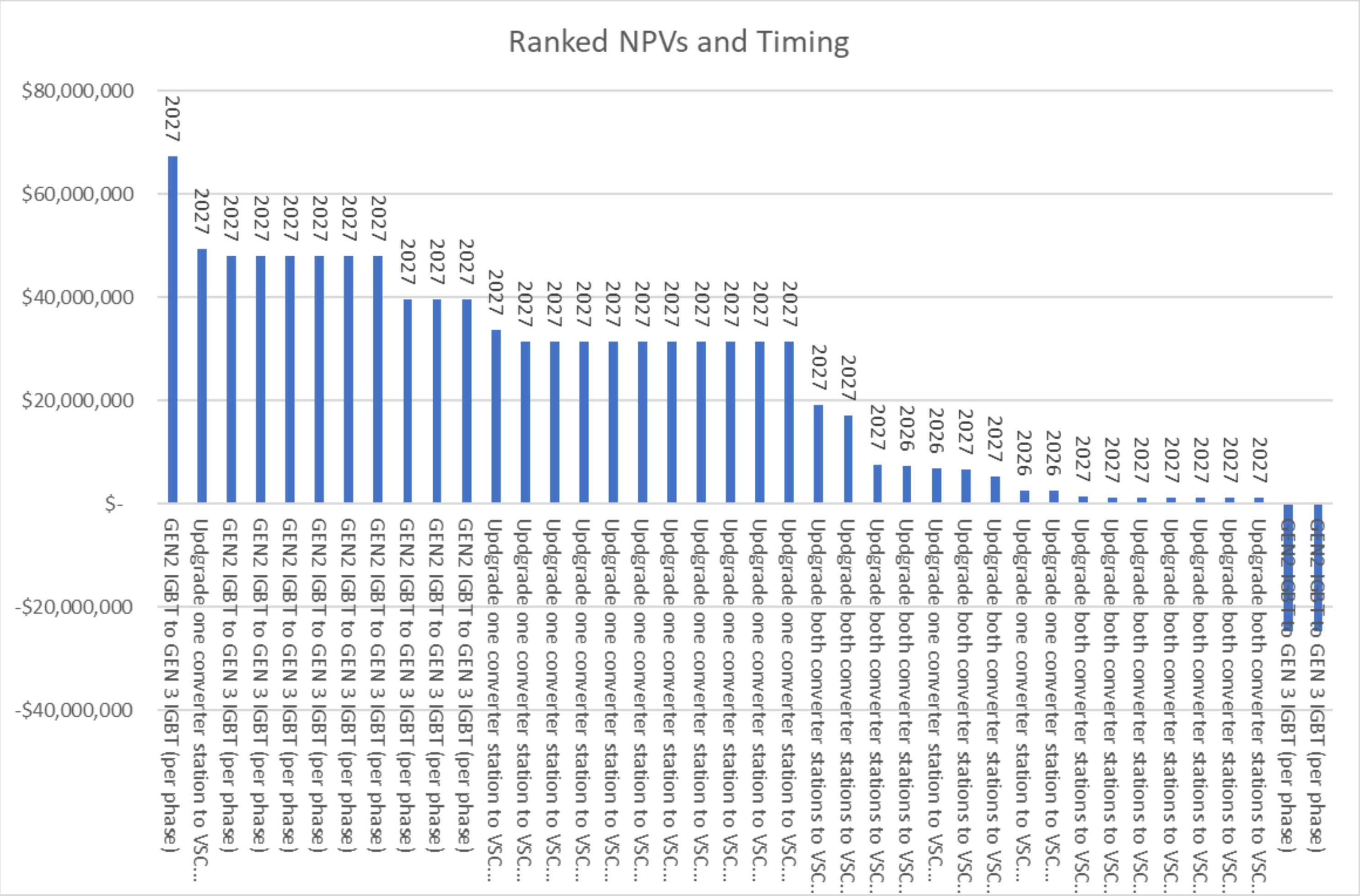
Approach

- For each scenario in the model, we have:
  - A starting stock of spares (which is the same across all scenarios - ~140 – based on our analysis of information provided by APA)
  - A forecast stock of spares for each year of the model, which is driven by:
    - the starting stock of spares (above),
    - less the number of assumed IGBT failures in that year (which depends on the randomly selected failure curve assigned to that scenario),
    - plus the additional stock of spares that are created *if* a CAPEX solution is assumed to be built under that scenario.
  - CAPEX solutions are automatically activated in the model in the year after the stock of spares reduces below 50.
  - Different CAPEX solutions (which, as stated earlier, are randomly ascribed to a scenario):
    - Create different amounts of spares:
      - GEN2 IGBT to GEN 3 IGBT (per phase) = 900;
      - Single converter station upgrade = 3000;
      - Both converter stations = 6000 (which is designed to in effect, remove the sparing issue, as this is a new technology)
    - Impose a different capital cost against that scenario (see previous slide); and
    - Impose a different outage cost against that scenario:
      - GEN2 IGBT to GEN 3 IGBT (per phase) = 70 days
      - Single and both converter stations upgrades = 150 days
  - The outage is assumed to be planned, with perfect foresight, hence the impact on the market (which is what is included in the NPV analysis, based on the difference between the "with" and "without" ML dispatch costs from the PLEXOS runs) is based on the minimum impact over 70 /150 consecutive days in the year the CAPEX solution occurs in the model

Approach

- If, after the initial capex solution occurs, the stock of spares breaches the 50 spare threshold again, then another CAPEX solution (of the same type) occurs.
  - Model caps # of investments, with the cap dependent on the CAPEX solution (e.g., only 6 “GEN2 to GEN3 (per phase)” capex solutions can occur; can’t replace 3 converter stations!).
- Marginal economic cost of not undertaking any capex solution is calculated for each scenario, based on the difference between the “with” and “without” ML PLEXOS outcomes, for the duration of it not being available from the first failure (until 2042 – which is the end of forecast time horizon in the NPV model)
  - We have also included an addition impact on dispatch costs, if ML is not available, and an outage on Heywood occurs in June / July (period when renewable droughts occur)
    - This has been informed by an additional PLEXOS run (with and without ML, but with full Heywood outage during an “at-risk period” between 10 June and 24 July (inclusive) every year in both runs)
    - We have simulated the risk of a Heywood outage based on a 1 in 100 year probability of occurrence, with the risk of outage in the ‘at risk period’ based on proportion of days
- Overall, the marginal economic decision the model is calculating reflects:
  - Costs:
    - Costs of the CAPEX investment(s) required to maintain ML
    - Costs of the planned outage associated with that CAPEX solution(s)
  - Benefits:
    - The cost to the market of not having ML (difference between the “with” and “without” ML wholesale dispatch costs)
    - Impact on dispatch costs if ML not available, and an outage at Heywood occurs in June / July period (periods when renewable droughts occur)

Preliminary Results - Run 1 (40 scenarios)



- Upgrading single phase is the best outcome under this model run.
- However, the two worst outcomes are also single phase upgrades - the NPV is negative as ~5-6 upgrades occur in these scenarios (driving 5-6 planned outages of ML)
- The timing of the first upgrade under all our failure rate scenarios is 2027 (with a small number at 2026).

Technology	Total NPV across scenarios		Ave NPV across scenarios	
GEN2 IGBT to GEN 3 IGBT (per phase)	$	424,567,436	$	35,380,620
Updgrade one converter station to VSC MMC	$	408,140,495	$	27,209,366
Updgrade both converter stations to VSC MMC	$	71,157,593	$	5,473,661

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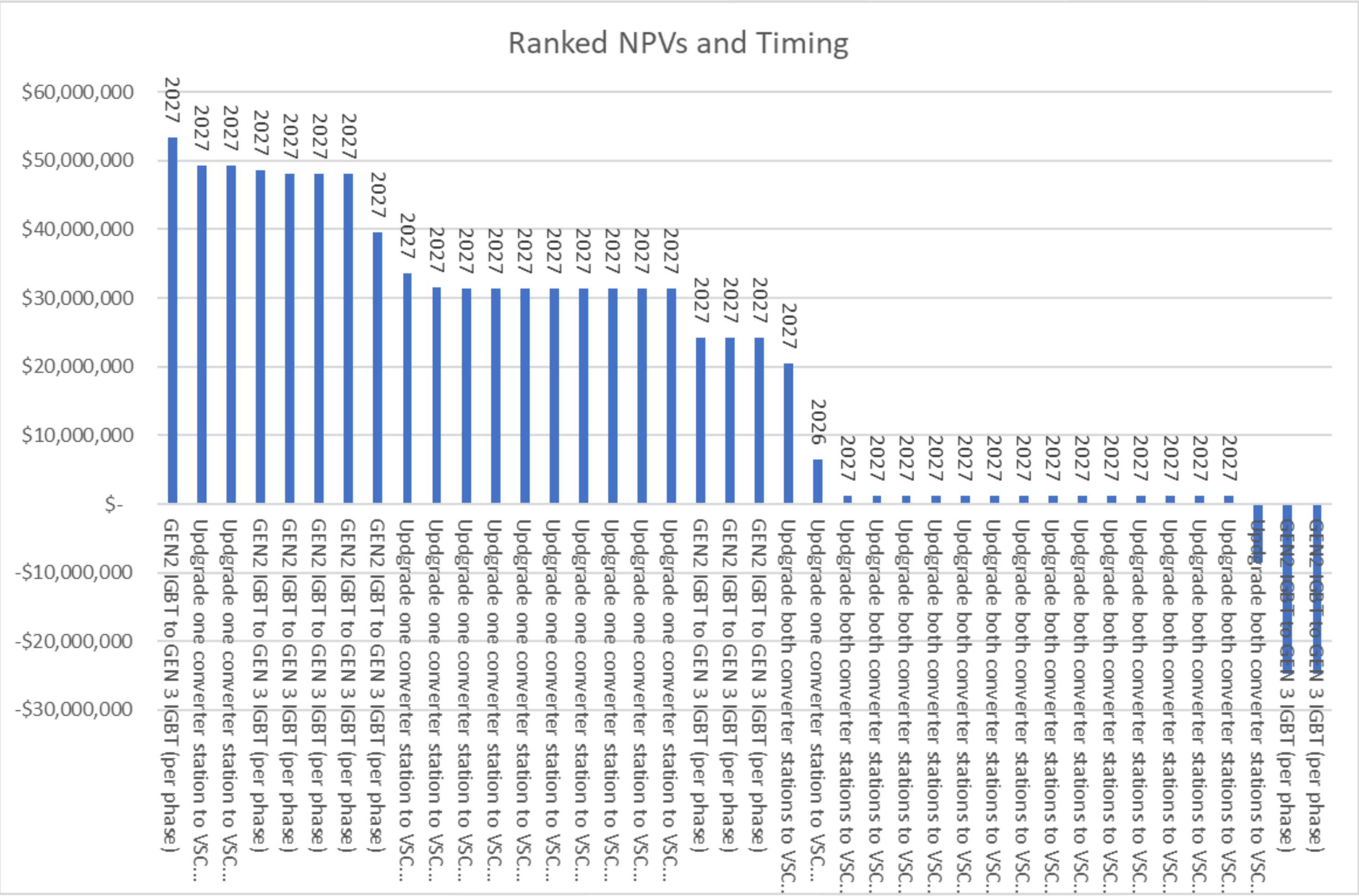
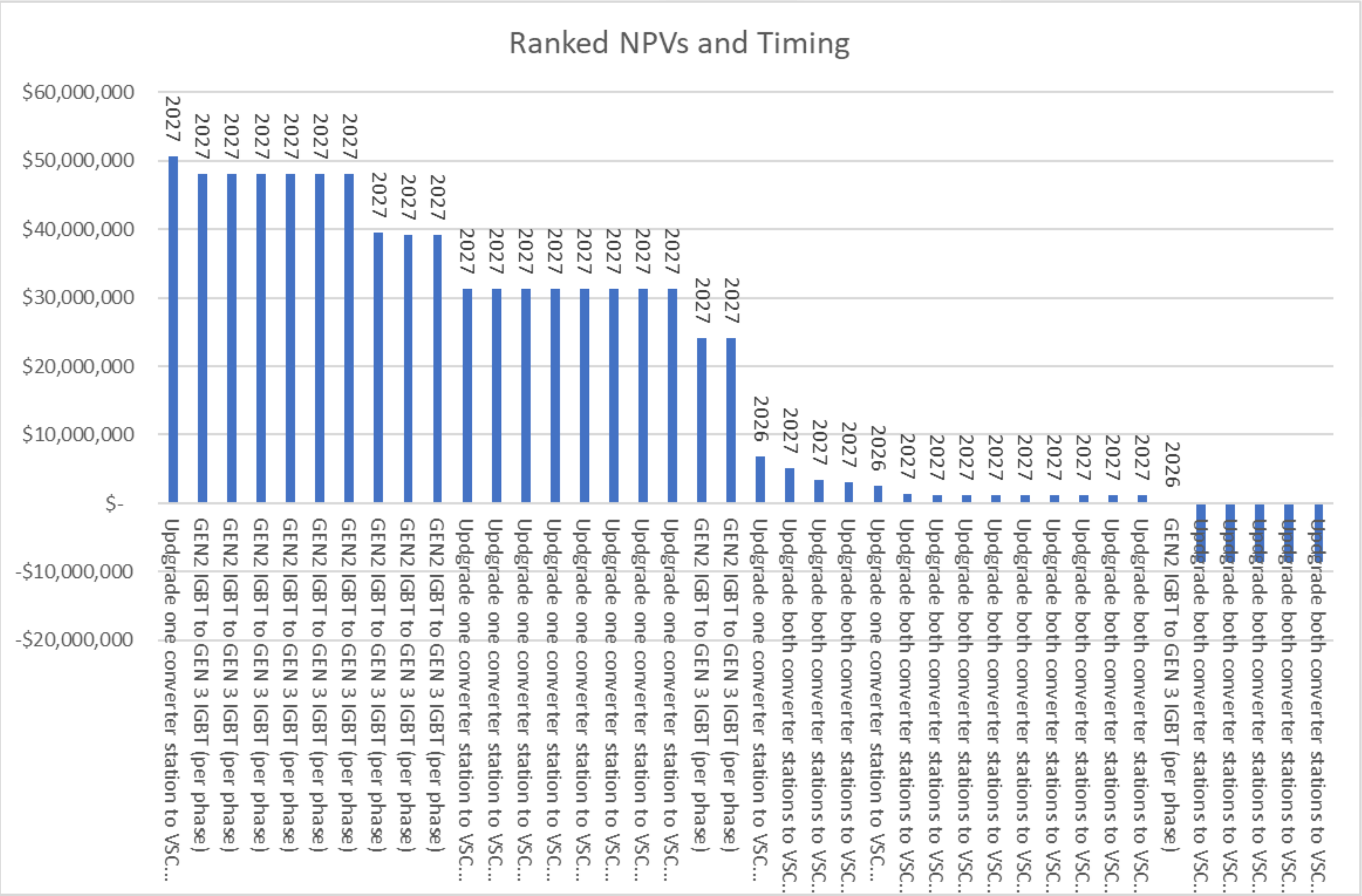
Preliminary Results – Run 2 (40 scenarios)



Technology	Total NPV across scenarios	Ave NPV across scenarios
GEN2 IGBT to GEN 3 IGBT (per phase)	$ 308,734,456	$ 28,066,769
Updgrade one converter station to VSC MMC	$ 420,836,943	$ 32,372,073
Updgrade both converter stations to VSC MMC	$ 28,355,756	$ 1,772,235

- In this run, upgrading a single phase and upgrading one converter station provide similar net benefits (based on their average NPV per scenario).
- Again, the timing of the first investment is 2027 (with a small number of scenarios at 2026).
- Upgrading both converter stations provides minimal economic benefit (although see caveats - end slide)

Preliminary Results – Run 3 (40 scenarios)



Technology	Total NPV across scenarios		Ave NPV across scenarios	
GEN2 IGBT to GEN 3 IGBT (per phase)	$	454,497,060	$	37,874,755
Updgrade one converter station to VSC MMC	$	310,612,533	$	28,237,503
Updgrade both converter stations to VSC MMC	-$	20,462,177	-$	1,203,657

- Again, upgrading a single phase is the best outcome in most cases.
- Upgrading both converter stations is the least economic, although we have not ascribed any value to the spares that are created.

Summary

- Preliminary results indicate:
  - Upgrading phase-by-phase or upgrading one converter station is likely to deliver net economic benefits under most scenarios (@WACC 6%)
  - The former is likely to be the most appropriate approach, although this depends on the failure rates
    - The NPV declines, the more failures are assumed and in turn, the more planned outages are required
- The timing of the initial capex solution under most scenarios is 2027
- Future CAPEX (beyond the first upgrade) is significantly impacted by the future failure rates.
  - The model can give an idea of the timing and number, however, as time goes by, better empirical information will become available upon which to base decisions.
  - A possible approach to quantifying likely failure rates (MTTF) of the future spares is to undertake accelerated life testing under high temp, voltage, environmental conditions. Used commonly for IGBTs in EVs and other power electronic components.
- None of the runs include the:
  - Small efficiency (~1% and 2%) improvements that occur if converter stations are upgraded
    - This is assumed to be immaterial.
  - Value of the IGBT spares that are created that could be sold to other businesses.
    - This might materially impact the 'both converter station' upgrade scenario (which creates a significant number of spare IGBTs, which could theoretically be sold to other businesses – however at this stage, the value is highly uncertain.
    - We will seek to determine a breakeven value for these spares (i.e., the value that would mean that the 'both converter station upgrade' is likely to be the most economic solution).

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