MITSUBISHI ELECTRIC
NON-SF6 SWITCHGEAR ROADMAP

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Agenda

- Mitsubishi Electric Power Products, Inc. (MEPPI)
- Mitsubishi Electric Corporation (MELCO)
  - Power Distribution Systems Center (PDSC)
- Breaker Market Strategy Overview
- Alternate Gas Technology Challenges
- Development Roadmap
- Vacuum Technology Challenges
- 72 kV VCB Development Status
- Discussion

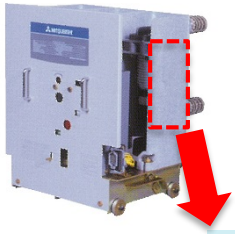
MEPPI Switchgear Divisions

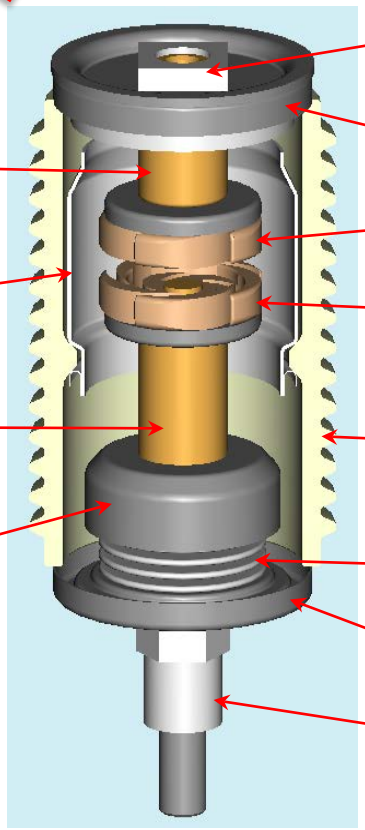
- High Voltage Switchgear Division
  - Established 1985
  - Manufactures dead tank Gas Circuit Breakers from 72 kV to 800 kV
  - Delivered nearly 25,000 breakers from our Pittsburgh, PA factory
  - Affiliated with the MELCO Factory at the Itami Works, Japan
- Electrical Distribution Division
  - Established 2005
  - Manufactures dead tank Gas Circuit Breakers from 38 kV to 72 kV
  - Manufactures free standing Vacuum Circuit Breakers from 5 kV to 38 kV
  - Delivered over 10,000 breakers from our Pittsburgh, PA factory
  - Affiliated with the MELCO Factory at the Marugame Works, Japan
- Substation Division
  - Established ~1993
  - Delivers GIS equipment and projects from 72 kV to 500 kV
  - Delivered over 120 projects and nearly 600 breaker-positions in North America
  - Affiliated with the MELCO Factory at the Itami Works, Japan

Mitsubishi Electric Corporation (MELCO)

Power Distribution Systems Center (PDSC)

Vacuum Interrupter





■Structure

- Compact and Lightweight Vacuum Interrupters
- Over 40 years of Experience with High Reliability

■Mitsubishi Series(1.5kV/4kA～84kV/31.5kA)

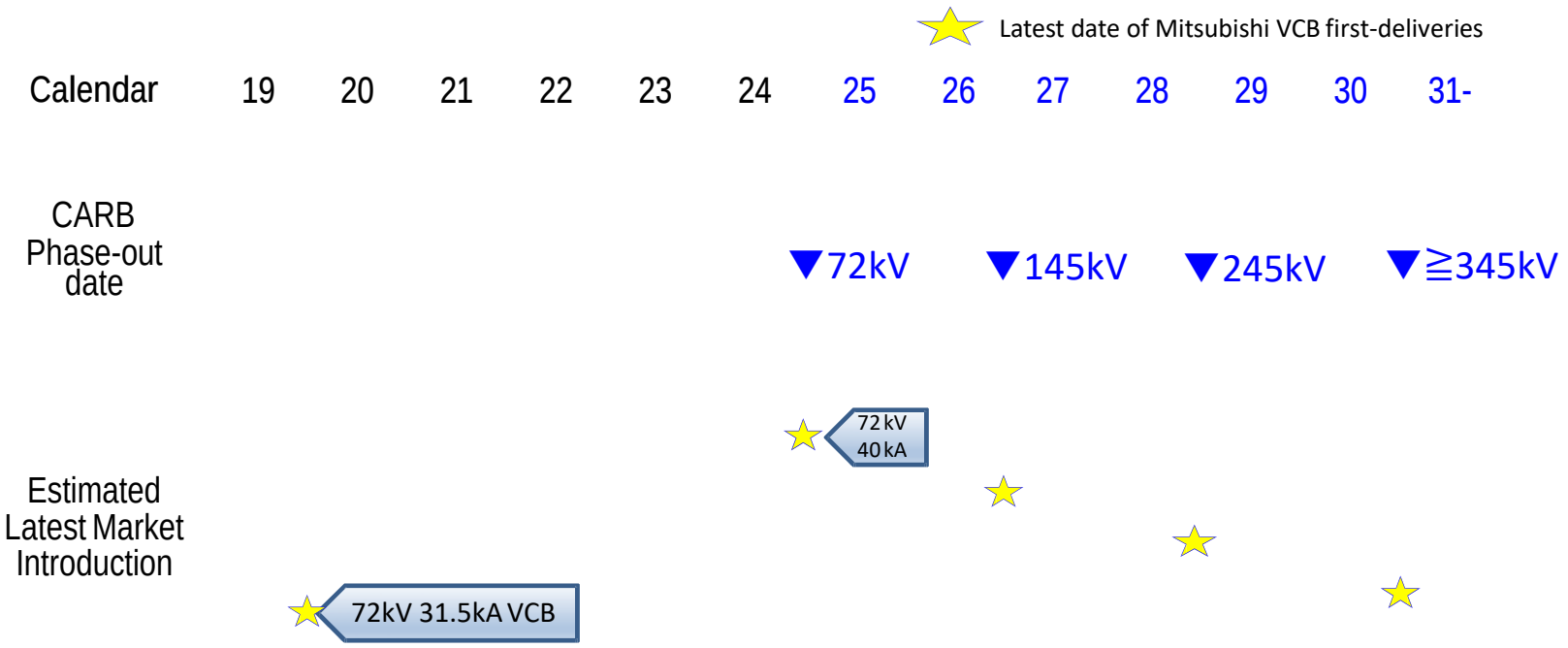
MELCO Vacuum Bottle Experience

1953	Rectifier Tubes such as Ignitron and Thyratron began being manufactured.
1962	Basic research of VI started in R&D.
1965	6.6kV Glass vessel type VI was developed.
1968	Metallic vessel type VI was developed.
1970	36kV-25kA VI was developed.
1973	Ceramic vessel type with Cu-Cr spiral contact was developed. 7.2kV-40kA VI was developed.
1980	VI export to European customers started. 12kV-50kA VI was developed.
1982	7.2kV-12.5kA low surge type VI was developed.
1985	Total production quantity exceeded 0.5 million.
1988	Production quantity of VI's exceeded 0.1 million per year.
1989	VI plant transferred to Marugame works. Total production quantity exceeded 1 million.
1995	Obtained ISO 9001 certification.
1998	7.2kV-40kA low surge VI was developed. Obtained ISO 14001 certification.
2000	12/24/36 kV dry-air CGIS introduced
2002	72/84 kV CGIS introduced
2004	Total production quantity exceeded 2.5 million.
2004	Medium Voltage project created at MEPPI.
2005	Medium Voltage Dept. formed at MEPPI to develop and launch 17 kV, 27 kV, and 38 kV F-VCB.
2011	JEC 72/84 kV dead-tank breaker (dry air) trialed in Japan
2013	Total Production quantity of VI's exceeded 3 million. MTBF = 5×10^9 hrs.
2018	e-F@ctory opened.

SF6 Alternative Gases

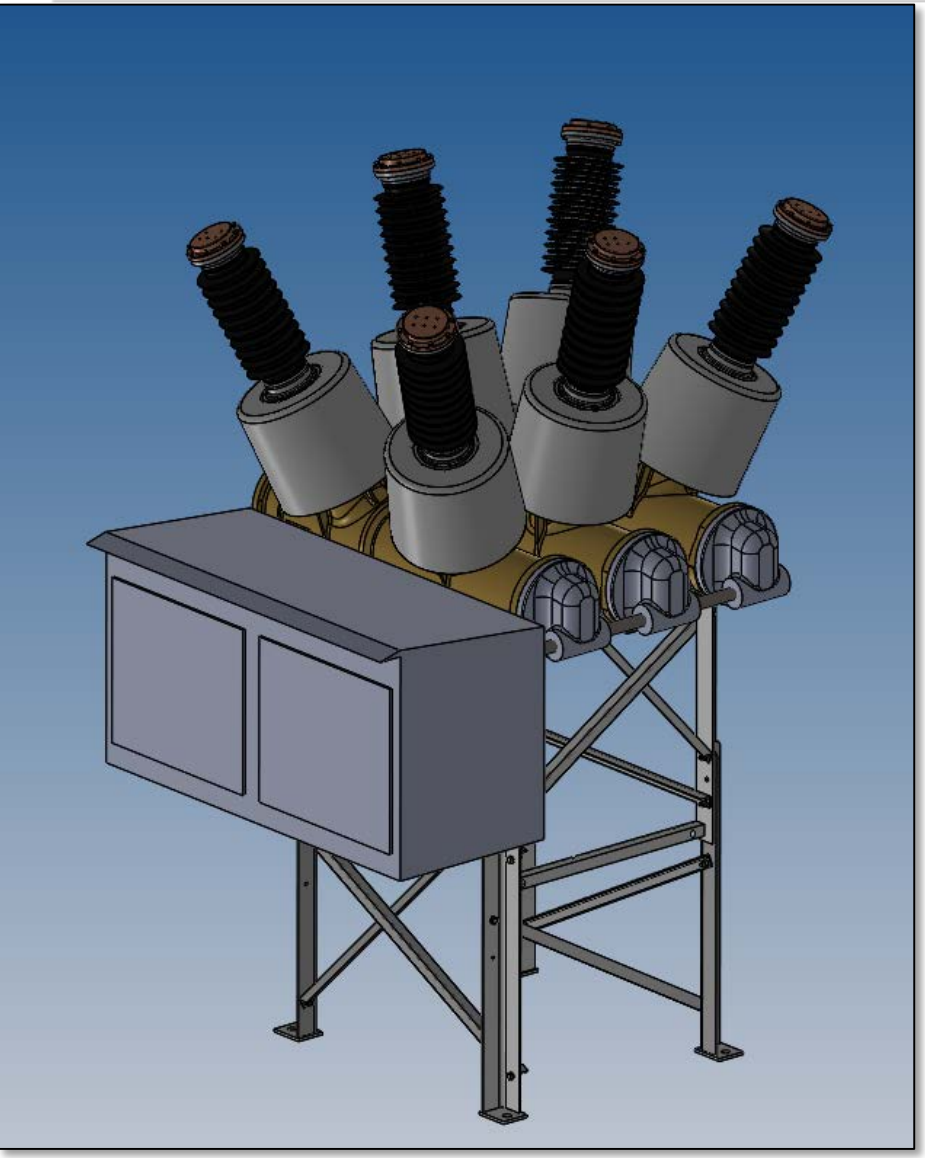
- To date there has been no alternative to SF6 gas that offers the same characteristics of :
  1. High dielectric strength
  2. High heat transfer capability
  3. Molecular stability
  4. Operational over a wide range of ambient temps
- Evaluation of alternative gases have found, in general, that they all have one or more undesirable characteristics that would make their adoption challenging
- Alternate gases may still require reporting because they are still considered a GHG in either pre-mixed or decomposed form
- No industry harmonized gas standards means utilities will require multiple gas handling carts in addition to legacy SF6 handling carts
  - Current suppliers have their own proprietary gas chemistries
- On that basis, MELCO made the decision to focus on a roadmap to develop an alternative to SF6 gas using vacuum technology

Mitsubishi Development Roadmap



- Building upon our experience with our line-up of 5 kV, 15 kV, 27 kV, and 38 kV vacuum breakers and 5 kV to 72 kV compact GIS, Mitsubishi is moving forward with a development roadmap for an alternative to SF6 gas with an all vacuum solution.
- With our next product launch of a 72 kV 31.5 kA breaker in early 2020, Mitsubishi is committed to meet or beat the CARB phase-out schedule for additional/higher ratings.

General Layout - 72DV32-20/30 Rating



The 72kV DTB is designed with the familiar MEPPI products in mind but taking advantage of a modern control and layout.

- Comparable in size to a 70SFMT40E breaker with the same foundation size as the 32F
- Utilizes well established MEPPI mechanism.
- Composite bushings matching the current 72kV design with only small changes to the end casting.
- CT's, mounting, and covers match existing 72kV designs.
- Rotary linkage with cabinet mounted on the side out from under the bus.
- Target Product Launch – April 2020

Example: 72DV32-20/30 Rating

PERFORMANCE REQUIREMENTS

BASE RATING:		
RATED VOLTAGE:	72.5kV	72.5kV
RATED SYMMETRICAL FAULT CURRENT:	40kA	31.5kA
BASE REFERENCE STANDARD:	ANSI C37	ANSI C37
RATED FREQUENCY:	60Hz	60Hz
ASYMMETRICAL X/R	17	17
TIME CONSTANT:	45	45
BREAKING TIME:	3 CYCLES	3 CYCLES
CLOSING TIME:	5 CYCLE (max)	5 CYCLE (max)
BREAKER RECLOSE DUTY:	O-0.3s-CO-15s-CO	O-0.3s-CO-15s-CO
EXTERNAL TO VST ENCLOSURE GAS:	Dry Air	Dry Air
EXTERNAL TO VST ENCLOSURE GAS PRESSURE:	101psi	101psi

OPERATIONAL PERFORMANCE:		
MECHANICAL LIFE:	(M2) 10,000	(M2) 10,000
LOAD CURRENT ELECTRICAL LIFE:	10,000	10,000
ELECTRICAL LIFE:	E2	E2
FULL CURRENT FAULT LIFE:	20	20
TEMPERATURE RANGE :	-50°C TO 50°C	-50°C TO 50°C

DIELECTRIC:		
1 MIN. DRY:	160kV	160kV
FULL WAVE WITHSTAND:	350kV	350kV
RATED NOMINAL CURRENT (MINIMUM):	2000A/3000A	2000A/3000A

SHORT CIRCUIT:		
TRV:	Two Parameter	Two Parameter
FIRST POLE TO CLEAR K_{pp} (Terminal):	1.5	1.5
AMPLITUDE FACTOR Kaf (Terminal & SL):	1.54	1.54
FIRST POLE TO CLEAR K_{pp} (Out of Phase):	2.5	2.5
AMPLITUDE FACTOR Kaf (Out of Phase):	1.25	1.25
RATED SHORT TIME CURRENT:	40kA	31.5kA
RATED SHORT CIRCUIT MAKING CURRENT:	104kA	82kA
MAXIMUM PERMISSIBLE TRIPPING DELAY:	2s	2s

CAPACITIVE CURRENT SWITCHING:		
OVERHEAD LINE CURRENT:	100A	100A
OVERHEAD LINE CURRENT RESTRIKE CLASS:	C2	C2

Notes:

Capacitor Single Bank testing is not included. Line charging is.

Reactor Switching will be possible based on system analysis, the same as SF6 DTB.

Challenges with Vacuum Interruption

- Vacuum is used for interrupting only and requires another material for insulating energized parts inside a pressurized vessel
  - This material may be compressed dry air, solid dielectric or a combination
  - This may increase physical sizes of equipment
- Vacuum interruption currently performs to X/R ratio of 17
  - Higher X/R could be considered a special purpose application
- Vacuum is generally challenged for capacitor switching
  - Cap switching could be considered a special purpose application
- Currently vacuum seems practical for interruption up to 145 kV with dry air insulation for the dielectric
  - Beyond that, a new insulating gas may be required to keep equipment size and cost within reasonable bounds
- Multiple breaks will be required at and above 245kV