Three Case Studies of High Reliability Power Systems

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Project No. 1: H-3 Tunnel

- 1.6 km (1 mile) long, twin-bore tunnel thru Koolau mountains
- Part of 26-km highway in Honolulu, Hawaii
- Tunnel connects Halawa valley to west and Haiku valley to east
- Cost: $1.3 billion (US) = 90% from FHWA + 10% from HDOT
Haiku Cross-Over Vault
4 Sources of power

For high reliability, 4 sources:
- 2 utility HV transmission circuits
- 1-500 kW emergency generator
- Numerous UPS and battery/inverter units
Utility power source

- 2-46 kV HECO transmission lines for high reliability
- Radial circuits terminate at portal substations: Halawa & Haiku
- Separate substations for redundancy
- 10 MVA, 46-12.47 kV transformer, fully sized for redundancy
HECO 46 kV
Incoming Ckt
HECO 10 MVA Substation
Emergency power sources

- Emergency diesel engine-generator: 500 kW, 480 V
- UPS units (15 min. battery capacity): computer-type loads
- Fast transfer battery/inverter units (90 min. battery capacity): HID lighting
500 kW Emergency Generator
S&C Electric
12 kV ATS
S&C Electric
12 kV ATS
Fuses
Emergency panelboards

Emergency Generator

Normal Power

ATS

UPS

Building Power and Lighting Emergency Panelboard
12.47 kV switchgear system

- Metal-clad switchgear
- Vacuum circuit breakers
- Draw-out
- Electrically operated
Split bus configuration

- Bus A = HECO Halawa H-3 substation
- Bus B = HECO Haiku H-3 substation
- Bus A tie feeder thru outbound tunnel via concrete duct bank
- Bus B tie feeder thru inbound tunnel via concrete duct bank
- Avoids coincident damage
Split bus configuration

HECO Halawa H-3 Substation

Halawa 12.47 kV SWGR

Bus A Tie Feeder

Bus B Tie Feeder

Rec.

N.O.

Send

Bus A

Bus B

HECO Haiku H-3 Substation

Haiku 12.47 kV SWGR
Tunnel lighting feeders

- 2-12.47 kV tunnel lighting feeders
- 7-12.47 kV ATSs and 7-150 kVA, 12.47 kV-480 V transformers:
- 5 cross-passages: 1, 3, 5, 7, 9
- 2 cross-over vaults: Halawa & Haiku
- Electrically-operated contactors, fast transfer battery/inverter units
Batteries for Emergency Lighting
Tunnel lighting feeders

- Halawa Bus B
- Emergency Generator
- ATS
- Bus B Tunnel Lighting Feeder (Typ. 4)
- 150 kVA
- 12.47 kV
- 480 V
- EO
- Ltg Panel
- FT B/I

- Halawa Bus A
- Emergency Generator
- ATS
- Bus A Tunnel Lighting Feeder
- 150 kVA
- 12.47 kV
- 480 V
- EO
- Ltg Panel
- FT B/I
Approach from Halawa Valley
Exit to Haiku Valley
12.47 kV swgr interlocking

- Most significant reliability feature
- Auto restoration following HECO loss, feeder or bus fault
- Control wiring w/interposing relays between Halawa and Haiku swgr
- Most common failure - loss of one HECO line
1 of 32
Tunnel Vent Fans
Loss of HECO restoration - 1

HECO Halawa H-3 Substation

Halawa 12.47 kV SWGR

Bus A

Bus B

N.O.

Loads

Bus B Tie Feeder

Bus A Tie Feeder

Bus B

Haiku 12.47 kV SWGR

Bus A

Bus B

N.O.

Loads

HECO Haiku H-3 Substation
Loss of HECO restoration - 2

Halawa 12.47 kV SWGR

Haiku 12.47 kV SWGR

Bus A Tie Feeder

Bus B Tie Feeder
Loss of HECO restoration - 3

Halawa 12.47 kV SWGR

Bus A
N.O.

Bus B

Load

Bus A Tie Feeder

Bus B Tie Feeder

Haiku 12.47 kV SWGR

Bus A
N.O.

Bus B

Load

HECO Haiku H-3 Substation
Loss of HECO restoration - 4

HECO Haiku H-3 Substation

Halawa 12.47 kV SWGR
Bus A
N.O.
Loads

Bus B Tie Feeder

Bus A Tie Feeder

Haiku 12.47 kV SWGR
Bus A
N.O.
Loads

Bus B

Load

Loss of HECO restoration - 4

Halawa 12.47 kV SWGR
Bus A
N.O.
Loads

Bus B Tie Feeder

Bus A Tie Feeder

Haiku 12.47 kV SWGR
Bus A
N.O.
Loads

Bus B

Load
Loss of HECO restoration - 5

HECO Haiku H-3 Substation

Halawa 12.47 kV SWGR
Bus A
N.O.

Bus B Tie Feeder

Haiku 12.47 kV SWGR
Bus A
N.O.

Loader
Loader
Loss of HECO restoration - 6

HECO Haiku H-3 Substation

Halawa 12.47 kV SWGR

Bus A

N.O.

Loses

Bus B

Loses

Haiku 12.47 kV SWGR

Bus A

N.O.

Loses

Bus B

Loses

Bus B Tie Feeder
Loss of HECO restoration - 7

Halawa 12.47 kV SWGR
Bus A
Closed

Haiku 12.47 kV SWGR
Bus A
Closed

Bus B Tie Feeder

HECO Haiku H-3 Substation

Loses

Loses

Loses
Loss of HECO restoration - 8

Halawa 12.47 kV SWGR
  Bus A
  Closed
  Loads

Bus B Tie Feeder

Haiku 12.47 kV SWGR
  Bus A
  Closed
  Loads
  Bus B
  Loads

HECO Haiku H-3 Substation
Local manual restoration

- Personnel required at both Halawa and Haiku swgr
- Local auto-manual switch (43AM)
- 43AM in manual to override switchgear automatic features
- Random operations will open and close other breakers
Remote manual restoration

- Through control room computer
- 43COMP is similar to local 43AM switch
- 43COMP is a control relay
- Energize 43COMP relay = manual
12.47 kV relay settings

- Very inverse OC relays set for max loading
- Coordination very difficult, many combinations
- Special setting for instantaneous relays
- Large inrush current from many transformers
480 V load centers

- Two 2,500 kVA, 12.47 kV - 480Y/277 V transformers
- Fully-sized, all 4 portal buildings
- Also split-bus configuration w/automatic restoration
- Restoration via local or remote
480 V restoration - 1

Bus A
Halawa or Haiku

2500/2800 kVA
12.47 kV-480 V

Bus 1, 480 V

N.O.

Bus B
Halawa or Haiku

2500/2800 kVA
12.47 kV-480 V

Bus 2, 480 V

 Loads

 Loads
480 V restoration - 2

Bus B
Halawa or Haiku

2500/2800 kVA
12.47 kV-480 V

Bus 1, 480 V

Load

Bus 2, 480 V

Load

N.O.
480 V restoration - 3

Bus B
Halawa or Haiku

2500/2800 kVA
12.47 kV-480 V

Bus 1, 480 V
Bus 2, 480 V
Closed

 Loads

 Loads
480 V restoration - 4

Bus B
Halawa or Haiku

2500/2800 kVA
12.47 kV-480 V

Bus 1, 480 V

Bus 2, 480 V

Closed

Loads

Loads
Biosphere 2 is a 3.15 acre closed ecosystem with 5 biomes:

1. Desert
2. Marsh
3. Savannah
4. Rainforest
5. Ocean
Project No. 2: Biosphere 2

- Original intent: experimentation for space travel
- Learn from sealing 8 people in closed system
- 1st mission: 2 years, September 1991
- Mission-critical: requires high reliability power system
Cogeneration power plant

- Biosphere 2 cogeneration power plant produces:
  - Electrical energy
  - Hot water for heating
  - Cold water for cooling
  - Waste heat from engine captured to run absorption chiller
Heart of electrical system is 4.16 kV double-bus system

Bus A & Bus B with metal-clad swgr

Two buses located in separate electrical rooms

Prevent coincident damage
Redundant 4.16 kV feeders

- Four 4.16 kV feeders total
- Bus A: two feeders, A1 & A2
- Bus B: two feeders, B1 & B2
- Only one feeder required to run Biosphere 2 experiment
Engine-generators, 4.16 kV

- 3 engine-generators, dual-fuel
- Standby & prime: 5,250 kW total
- G1, standby generator, 1,500 kW
- G2, prime generator, 2,250 kW
- G3, prime generator, 1,500 kW
- 2 generator breakers to Bus A & B
480 V double-ended subs

- Power plant parasitic loads from load center 27LC02
- Double-ended substation
- Two 2,000 kVA, 4160-480 V transformers, fully-sized
- Split bus configuration: main-tie-main
Utility as back-up

- Energy center generators provide primary power
- Electric utility serves as back-up
- One 3,750 kVA, 12.47-4.16 kV transformer
- Import of 50 kW, APTL controller
Future solar PV array

- Provisions for 3rd power source:
- 500 kW solar photovoltaic array
- DC to AC inverter
- 750 kVA, 480-4160 V step-up transformer
Project No. 3: Motorola

- HV Distribution System Upgrade
- Design/build for Motorola plant in Plantation, Florida
- 30-year-old electrical system
- Failures: Al feeder cables and transformer
Project No. 3: Motorola

- **Prime directive:** keep production lines running
- **Downtime costs:** $300,000 per hour
- **Motorola required highly reliable power system**
Old 13.2 kV utility

- Two FP&L services at 13.2 kV
- Shared with other customers
- 1. Vault with transformers & 480 V feeders
- 2. 13.2 kV fused switches & 13.2 kV feeders
- Radial feeders to transformers
New 23 kV distribution

- New 23 kV substation for two 23 kV FP&L feeders
- 23 kV permits higher power transfer
- Peak demand = 10 MW
- Dedicated feeders from FP&L substation
23 kV substation

- Dedicated electrical room
- Metal-clad swgr, 27 kV class, 750 MVA, 3 cycle, vacuum breakers
- Split-bus configuration: main-tie-main, fully redundant
- Provisions for 3rd bus for >15 MW load
23 kV FP&L vault

- Adjacent FP&L vault: HV switches, relays, meters
- Fiber optic link from FP&L substation
- Direct communication for breaker & relay status
Electronic relays

- All relays: electronic solid-state
- Two main breakers had back-up relays
- RS-232 link permitted uploading of settings
Switchgear control power

- Combination of AC and DC power
- AC: close vacuum circuit breakers
- DC for critical loads:
  1. Trip circuit breakers
  2. PLC
  3. Relays
Control power from PTs

- AC control power from 2 PTs at both 23 kV buses
- One bus may be unavailable
- ATS to select either bus
DC power from batteries

- DC power from battery banks
- 2 battery banks for increased reliability
- ATS selects either battery bank
  - Primary: gel cell batteries
  - Secondary: sealed cell batteries
PLC

- PLC used to control swgr
- Actuates local annunciator board
- Sends automatic alarm to electrical personnel, pager on weekends
PLC alarms (partial list)

- PLC internal failure
- Switchgear battery ground fault
- Switchgear DC bus failure
- Switchgear battery charger failure
- Main breaker relay failure
- Closed transition failure
- Air conditioner failure
PLC high output cards

- Increased reliability with direct tripping of breakers
- Use PLC high output cards
- Advantages: less time to trip, less component failure
- Old method: interposing relay
Closed transition transfer

- Unique: closed transition transfer (i.e., make-before-break)
- No interruption to plant
- Usually not allowed by utility
- Restrictions: 1 second, frequency check, synch check
Closed transition transfer

- Normal configuration: split-bus, open bus-tie
- If: loss of one FP&L feeder
- Then: close bus-tie
- Then: open main
- Reverse upon return
Ground grid

- Highest quality ground: electrolytic ground rods
- Copper-clad steel ground rods at intermediate points
- Interconnected with bare copper conductors
Halo ground

- Added safety feature: halo ground
- Solid copper ground buses
- At ceiling, front & behind 23 kV swgr line-up
- Attach ground leads during maintenance, rack-out breakers
HV cables

- For 23 kV circuit, standard cable rating would be 25 kV
- Decrease HV stresses, next rating of 35 kV
- Shielded, EPR insulation, 100%, MV-105, copper
HV terminations

- Increased reliability: HV molded elbows
- Superior connection: cable to bus w/metal insert
- Contains HV corona
- Old method: stress cone terminations with exposed energized surfaces
480 V double-ended subs

- Improved reliability, 480 V double-ended substations
- Split-bus: main-tie-main
- Fully-rated transformers, 23 kV-480 volts
Best cast coil transformers

- No spill containment
- No liquid (fire or environmental)
- Better surge capability, epoxy cast over coils
- Less space required, no fins
- Fewer maintenance tests (e.g., no dissolved gas-in-oil)
Closed transition transfer

- 480 V swgr repeats closed transition transfer function
- Could parallel 23 kV lines at 480 V swgr
- Safeguard: control wires as permissive in 480 V swgr PLC
- Check for status of 23 kV breakers
Transformer HV switch

- Transformer directly coupled to 23 kV fused air switch
- Fuse provides internal transformer fault protection
- Local disconnecting means for maintenance
Lightning arresters

- HV lightning arresters: transformer primary
- Metal-oxide, 15.8 kV
- Protects from damaging HV spikes & surges
- Added reliability: 2nd set of arresters, line side of switch
Summary: H-3 Tunnel

- 4 sources of power for critical loads
- Features: redundancy and flexibility
- Significant: 12.47 kV swgr interlocking
- Immediate auto restoration of power
- High reliability power system
Summary: Biosphere 2

- 4.16 kV dual-bus
- Separate electrical rooms
- Redundancy in 4 feeders
- 3 engine-generators
- Utility as back-up
- High reliability power system
Summary: Motorola

- Increase distribution voltage from 13.2 to 23 kV
- Split-bus 23 kV & 480 V swgr
- Double-ended substations
- PLC for closed transition transfer
Summary: Motorola

- Cast-coil transformers
- 35 kV cables for 23 kV circuits
- Molded elbows for HV terminations
- Dual lightning arresters
- High reliability power system
Questions?