Study Committe B4

DC System and power electronics

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HVDC System Operating Performance Analysis Via Statistical Analysis on O&M Data with RAM Basis

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Summary

In Korea, there are two bipole lines, #1 HVDC and #2 HVDC, to supply power to Jeju Island, which is about 100km from the mainland.

Recently, due to rapid growth of load within the Jeju region, in case of power outage on the aforementioned lines, power system of Jeju Island would have become very weak or even resulted in black-out.

Therefore, in order to evaluate operating performance of HVDC system, Operation & Maintenance Data with RAM(Reliability, Availability, Maintainability) Basis from CIGRE S.C has been analyzed for comparison between Operating performance of HVDC system within Jeju Region in Korea and the average operating performance of the HVDC system in the world.

We conducted operating performance evaluation for the following 5 items.

1. Global HVDC System performance Evaluation (Note that Table1)

2. #1 HVDC System Operating Performance Evaluation (Note that Table2)

3. #2 HVDC System Operation Performance Evaluation (Note that Table3)

4. Statistical Analysis on Fault of #1HVDC for Recent Five(5) Years (2013 ~2017) (Note that Table4, 5, 6)

5. Statistical Analysis on Fault of #2HVDC for Recent Four(4) Years(2014 ~ 2017) (Note that Table7, 8)

As a result of analysis,

In overall, #1, 2 HVDC operation performance is far better than the average of all the other projects in the world.

The reason of such result is more maintenance works with scheduled outage in order to prevent black-out of jeju Power System in Korea.

Keywords

- **Energy Availability : HVDC Operation Performance Ratio excluding scheduled outage and forced outage**
- **Scheduled Energy Unavailability : It means the outage ratio of HVDC Operation due to overhaul and when repairing**
- **Forced Energy Unavailability : It means the outage ratio of HVDC Operation due Trip by protective action and unexpected failure**
- **Equivalent Outage Hours : Time to consider partial dose reduction**
- **RAM : Abbreviation for Reliability, Availability, Maintainability**

Introduction

- **Domestic HVDC operating performance has been evaluated with RAM statistic analysis for each #1 HVDC and #2 HVDC in commercial operation in Korea**
- **Comparison analysis with the performance evaluation on global HVDC systems for the twenty(20) years('95~'14) from CIGRE**
- **This paper deals with objective judgement on #1,2 HVDC operability and how to utilize RAM analysis result in the future**

Figure-1 #1 HVDC Converter Station

Figure-2 #2 HVDC Converter Station

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HVDC Evaluation and analysis

1. HVDC System performance evaluation

- **Table 1, 2, 3 is showing energy usability, availability, and unavailability. Energy usability indicates annual maximum continuous power transmission capacity of HVDC in percentage**
- **Energy availability indicates actual possible power transmission capacity excluding scheduled and forced outages**

(Table 1) CIGRE Global HVDC System Performance

Category	Unit	Case1	Case2	Case3	Case4	Case5	Case6
Energy Usability[U]	%	48.07	48.45	42.83	43.26	50.16	50.46
Energy Availability[EA] (including scheduled and forced outages)	%	94.22	95.85	93.89	95.11	95.70	95.87
Energy Availability[EA*] (excluding forced outages)	%	98.31	98.37	97.69	97.73	97.87	97.80
Scheduled Energy Unavailability [SEU]	%	4.09	2.53	3.80	2.62	2.17	1.93
Forced Energy Unavailability [FEU]	%	1.69	1.62	2.31	2.27	2.13	2.20
Equivalent Outage Hours[EOH]	hr	506.33	363.54	535.24	428.36	376.68	361.79

Case1–Average of 1995~2014 (68 Samples)

Case2–Average of 1995~2014 excluding scheduled outages of more than one month (64 Samples)

Case3–Average of HVDC facility completed in 1989~2000, #1 HVDC comparison subject (24 Samples)

Case4–Average of HVDC facility completed in 1989~2000 excluding scheduled outages for one month or longer, #1 HVDC comparison subject (23 Samples)

Case5–Average of HVDC facility completed after 2004, #2 HVDC comparison subject (18 samples)

Case6–Average of HVDC facility completed after 2004 excluding scheduled outages for one month or longer, #2 HVDC comparison subject (16 Samples)

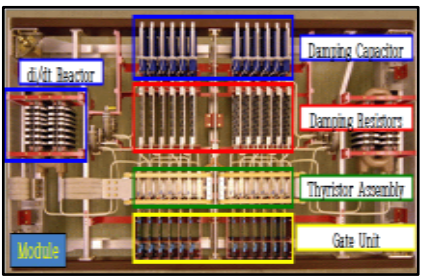

Figure-3 #1 HVDC Thyristor Valve Diagram

(Table 2) #1HVDC System Operating Performance Evaluation for Recent Five(5) Years

Category	Unit	2013	2014	2015	2016	2017	Avg.	Case2	Case4	Case6
Energy Usability[U]	%	33.57	23.68	22.43	26.86	27.10	26.73	48.45	43.26	50.46
Energy Availability[EA] (including scheduled and forced outages)	%	96.35	92.70	93.93	94.82	95.68	94.70	95.85	95.11	95.87
Energy Availability[EA*] (excluding forced outages)	%	99.54	99.90	100	99.85	99.97	99.85	98.37	97.73	97.80
Scheduled Energy Unavailability [SEU]	%	3.190	7.198	6.070	5.027	4.286	5.15	2.53	2.62	1.93
Forced Energy Unavailability [FEU]	%	0.460	0.098	0.000	0.149	0.033	0.14	1.62	2.27	2.20
Equivalent Outage Horus [EOH]	hr	319.7	639.1	531.7	453.4	378.3	464.4	363.5	428.3	361.7

(Table 3) #2HVDC System Operation Performance Evaluation for Recent Four(4) Years

Category	Unit	2014	2015	2016	2017	Avg.	Case2	Case4	Case6
Energy Usability[U]	%	28.47	32.9	37.01	45.24	35.91	48.45	43.26	50.46
Energy Availability[EA] (including scheduled and forced outages)	%	99.54	97.00	96.8	97.57	97.73	95.85	95.11	95.87
Energy Availability[EA*] (excluding only forced outages)	%	99.63	99.90	99.92	99.99	99.86	98.37	97.73	97.80
Scheduled Energy Unavailability [SEU]	%	0.089	2.895	3.114	2.423	2.13	2.53	2.62	1.93
Forced Equivalent Unavailability [FEU]	%	0.372	0.107	0.082	0.008	0.14	1.62	2.27	2.20
Equivalent Outage Hours[EOH]	hr	40.38	262.9	279.9	212.9	198.8	363.5	428.3	361.7

2. Statistical Analysis on Fault of #1HVDC

- **Statistical analysis on fault of #1HVDC for recent 5 years is as below Table4**
- **Indicates highest number of forced outages on AC facillty and highest number of scheduled outages on thyristor valve**

Figure-3 Photo at the time of replacement Thyristor

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Category	No. of Outage			AOD (hr)			EOD (hr)		
	Forced	Scheduled	Total	Forced	Scheduled	Total	Forced	Scheduled	Total
AC-E	9	3	12	89.66	13.21	102.88	37.98	6.18	44.16
V	0	30	30	0.00	165.70	165.70	3.112	64.62	67.73
C-P	5	2	7	14.76	12.13	26.89	7.60	7.87	15.47
DC-E	1	2	3	4.150	9.53	13.68	3.11	6.10	9.21
O	0	2	2	0.000	6.83	6.83	0.00	2.562	2.56
TL	0	3	3	0.000	47.61	47.61	0.00	35.71	35.71
EXT	0	1	1	0.000	1.25	1.25	0.00	0.938	0.938
PM	0	17	17	0.000	2133.6	2133.6	0.00	1372	1372

- AC-E : All main AC equipment at converter station including AC auxiliary power, valve cooling system, AC C&P, etc.
- V: All valve components
- C-P: All equipment for HVDC control, monitoring, protection, except ones included under AC-E
- DC-E: All HVDC equipment not included under AC-E, V, C-P
- O: Human error or fault due to the unknown
- TL: DC power cable, underground cable, submarine cable or cable terminal related equipment
- EXT : AC network fault outside of converter system
- PM : Planned maintenance with scheduled outages

(Table 5) Forced/Scheduled Outages due to AC Facility for Recent Five(5) Years

Category	No. of Outage			AOD (hr)			EOD (hr)		
	Forced	Scheduled	Total	Forced	Scheduled	Total	Forced	Scheduled	Total
2013	5	1	6	70.250	3.267	73.517	28.531	2.450	30.981
2014	2	0	2	8.267	0.000	8.267	5.269	0.000	5.269
2015	0	0	0	0	0	0	0	0	0
2016	1	1	2	6.900	5.433	12.333	2.587	2.038	4.625
2017	1	1	2	4.250	4.517	8.767	1.594	1.694	3.288

(Table 6) Forced/Scheduled Outages of #1 HVDC due to Valve Equipment for Recent Five(5) Years

Category	No. of Outage			AOD (hr)			EOD (hr)		
	Forced	Scheduled	Total	Forced	Scheduled	Total	Forced	Scheduled	Total
2013	0	4	4	0.000	39.900	39.900	0.000	14.962	14.963
2014	0	6	6	0.000	37.267	37.267	0.000	13.975	13.975
2015	0	6	6	0.000	31.883	31.883	0.000	11.956	11.956
2016	0	9	9	0.000	40.967	40.967	0.000	15.363	15.363
2017	0	5	5	0.000	15.683	15.683	0.000	8.369	8.369

3. Statistical Analysis on Fault of #2HVDC

- Statistical analysis on fault of #2HVDC for recent four years is as below Table 7
- It indicates that highest number of forced outages have been caused due to control system and optical communication system.

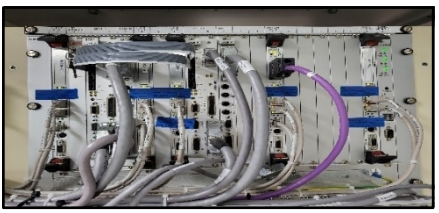

Figure-4 #2 HVDC Control Equipment

(Table 7) Statistical Analysis on Fault of #2HVDC for Recent Four (4) Years

Category	No. of Outage			AOD (hr)			EOD (hr)		
	Forced	Scheduled	Total	Forced	Scheduled	Total	Forced	Scheduled	Total
AC-E	3	2	5	7.997	6.938	14.93	3.999	3.469	7.468
V	0	1	1	0.000	2.183	2.183	2.885	1.092	3.976
C-P	17	17	34	44.73	45.81	90.54	29.43	43.84	73.27
DC-E	1	0	1	2.885	0.000	2.885	2.885	0.000	2.885
O	4	12	16	22.136	2.761	24.897	13.470	2.381	15.85
TL	0	3	3	0.000	8.763	8.763	0.000	4.382	4.382
EXT	0	0	0	0.000	0.000	0.000	0.000	0.000	0.000
PM	0	12	12	0.000	982.1	982.1	0.000	691.99	692.00

(Table 8) Forced/Scheduled Outages of #2HVDC due to Control System For Recent Four(4) Years.

Category	No. of Outage			AOD (hr)			EOD (hr)		
	Forced	Scheduled	Total	Forced	Scheduled	Total	Forced	Scheduled	Total
2014	5	4	9	30.583	6.817	37.400	30.583	6.725	37.400
2015	7	4	11	10.707	16.351	27.058	10.707	15.867	27.058
2016	1	3	4	3.042	13.954	16.996	3.042	12.558	16.996
2017	1	3	4	0.404	8.693	9.093	0.400	8.693	9.093

Conclusion

- As per RAM analysis results on #1 HVDC in recent five(5) years and #2 HVDC in recent four(4) years
- Their operating performance is the result of efficient operating
- In the future, the prospect of HVDC market is that there will be more PTP or BTB projects expanding the market.
- This paper addresses regarding operating performance evaluation on HVDC system in operation in Korea
- It is expected that RAM analysis introduction and utilization on HVDC project in construction will enable efficient management of converter station, supporting stable operation of HVDC facility