Study Committee B1

Insulated Cables

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Availability modelling of submarine high voltage cable systems

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Motivation

- Offshore cable systems are becoming significant components in the future power system in the wake of the energy transition:
  - Export cables – Offshore Windfarms
  - Submarine interconnectors
  - Offshore HVDC grid concept
- As the penetration of submarine power cables is increasing:
  - Essential need for a detailed model for cables availability estimation considering significant influencing factors
- Main contribution of this paper:
  - To propose a properly detailed model for the availability modelling of submarine cables with following influencing factors:
    - Adverse weather condition
    - Route survey, inspection and maintenance

Method/Approach

- Markov chain is used as a modelling method
- Assumptions:
  - Constant transition rates between states
  - Adverse weather condition as the significant limiting factor for offshore activities
  - Cables protection (not being exposed) as the main barrier against external threats
  - Cable route survey, inspection and maintenance as the main preventive action to reduce the failures
  - Other influencing factors such as visibility to the other mariners, preparedness agreements/plans, etc can be considered in the transition rates, for example, in the failure rates, repair rates, repair preparation rate, etc.

Objects of investigation

- This paper considers an offshore section of a submarine cable system as an object of study in general, and not aimed to study the availability of an overall system including the sealing ends, joints, etc.

Proposed model

- Working modes:
  1. Operating/Protected (O/P) - Safe
  2. Operating/Exposed (O/E) - Unsafe
  3. Planned outage (PO)
  4. Forced outage - Preparation for Repair (FO/P)
  5. Forced outage - Marine Repair Operation (FO/R)
- Two weather conditions:
  - Normal: all transitions are in place
  - Adverse:
    - no transition from states representing offshore activities
    - Possible to consider as many adverse weather specific parameters
  - Transition rates: $n_a = \frac{1}{N}, a_n = \frac{1}{s}$

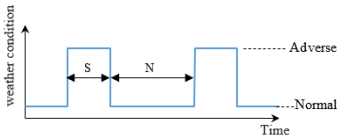

Figure 1 Average weather duration profile

- Figure 2 shows the proposed state transition diagram.

Discussion

- Implementing the model, reliability indicators can be calculated including:
  - Probablity of staying in states
  - Mean Time To Failure (MTTF)
  - Mean Down Time (MDT)
  - Availability (A) and Unavailability (U)
- Model Performance:
  - Base parameters: Table 1
  - Simulation results: Table 2
  - Sensitivity study: Figure 3

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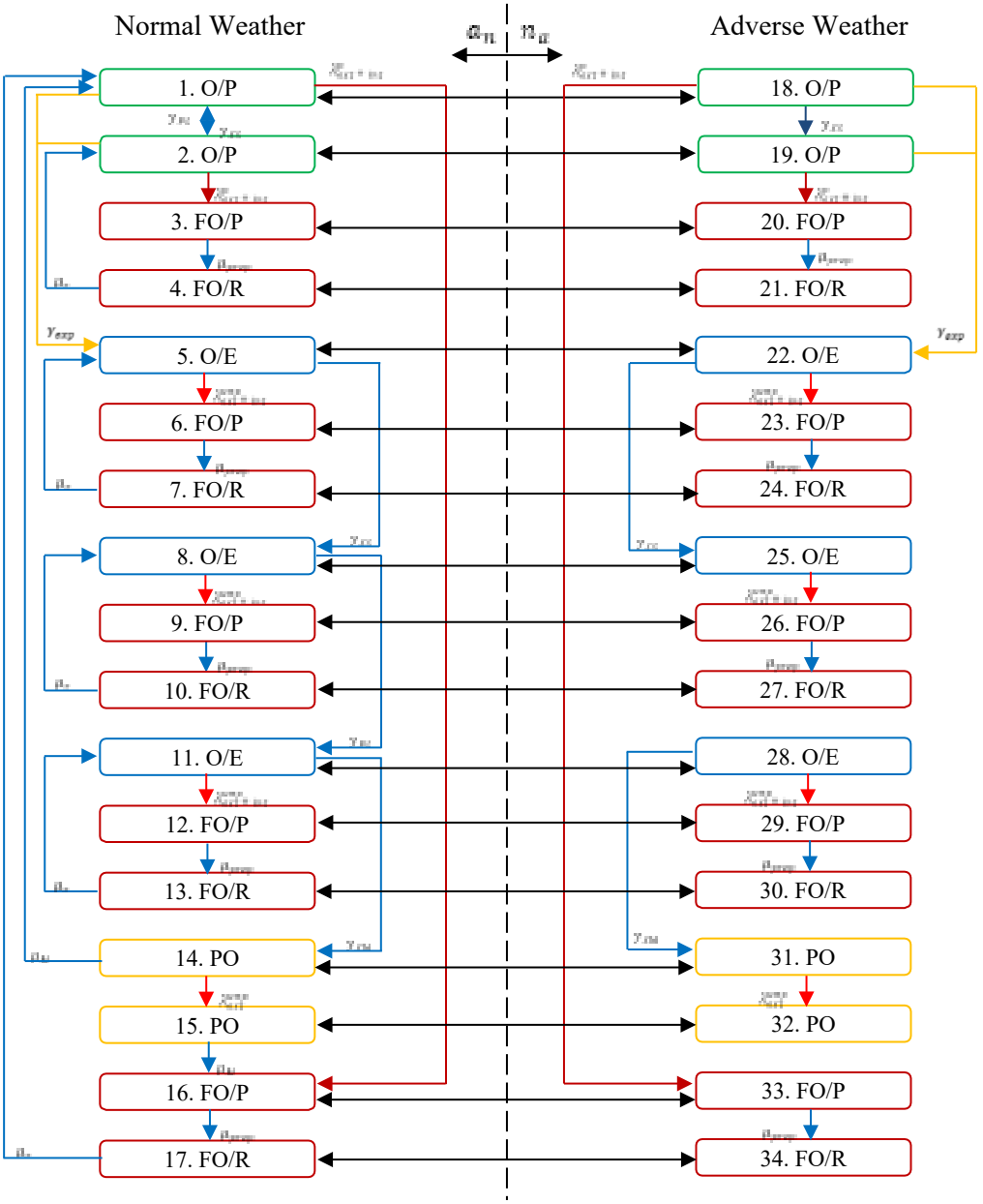

Figure 2

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Table 1 Model parameters-base case

Model Parameters	$\lambda_{rst+int}$	$\lambda_{RST+int}$	α_n	n_a	T_{exp}	T_{SS}	T_{PS}	T_{SM}	P_{PM}	P_{prep}	P_F
event/year	0.008	0.095	10	1.1	0.25	0.5	18.25	6.1	26.1	8.7	17.4

Table 2 Simulation results-base case

A, %	U_{PO}, %	U_{PO}, %	A_{safe}, %	A_{unsafe}, %	MTTF, years	MDT, days
98.48	0.74	0.77	63.18	35.30	27.6	67.4

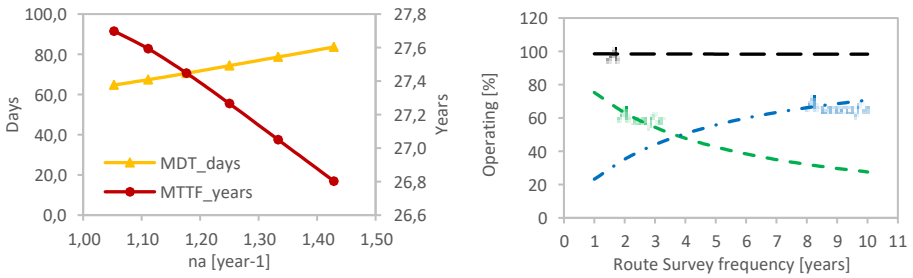

Figure 3 Left) Sensitivity of MDT and MTTF to the adverse weather condition, Right) Sensitivity of the availability, safe and unsafe operation probabilities to the route survey/inspection frequency (ref. to Figure 2)

Conclusion

- A detailed conceptual availability model based on Markov process is presented in this paper
- The influencing factors of adverse weather condition, cable route survey/inspection and maintenance scheduling are considered in the reliability indices such as overall availability, forced outage, planned outage as well as MTTF and MDT.
- The proposed model enables doing sensitivity studies on the influencing factors that assists the cable operators for an efficient future planning.
- The details introduced in the model enable the cable operators to have an estimation of different states probabilities that can be used for further analysis:
  - The costs of the route survey/inspection and maintenance/repair operations can be included for the optimization of the route survey frequency that requires to have the probabilities of being in states wherein the route surveys, maintenance and cable repair operations are undergoing, which are of the proposed model outputs.

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