Development of an Integrated Extreme Wind, Wave, Current, and Water Level Climatology to Support Standards-Based Design of Offshore Wind Projects

Technology Assessment and Research Project #672

IEC 61400-3 Table 1 Design Load Cases (DLCs)

APPENDIX A

APPENDIX A. IEC 61400-3 Table 1 Design Load Cases (DLCs)

Metocean return periods of interest will be identified using the IEC 61400-3 offshore wind turbine design standard. The table below summarizes the applicable Design Load Cases (DLCs). In this table, the DLCs are indicated for each design situation by their associated metocean conditions and operational behavior of the control system, fault scenarios, and other events. Abbreviations are defined at end of table.

Simulations considering power production under normal operation are considered in the 1.x-series DLC. The 2.x-series DLC considers power production with fault occurrences, each of which triggers a shutdown of the turbine. The 6.x- and 7.x-series DLCs consider parked (idling) and idling with fault scenarios, respectively, under extreme 1- and 50-year return periods.

For DLCs 2.x and 7.x, which involve fault conditions, the IEC standard requires selection of the faults with the worst consequences, and these are chosen based on common design-driving faults gleaned from experience in other loads analyses.

Metocean conditions also are required as input for the start-up, normal shutdown, and emergency shutdown events of DLCs 3.x, 4.x, and 5.x, as well as the 8.x-series cases that relate to transport, assembly, maintenance, and repair.

Table 1 – Design Load Cases

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
1.x Power production	1.1	NTM $V_{in} < V_{hub} < V_{out}$ RNA	NSS $H_s = E\,[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL	For extrapolation of extreme loads on the RNA	U	N (1.25)
	1.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*
	1.3	ETM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E\,[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.4	ECD $V_{hub} = V_r - 2\ m/s$, V_r, $V_r + 2\ m/s$	NSS (or NWH) $H_s = E\,[H_s \mid V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N
	1.5	EWS $V_{in} < V_{hub} < V_{out}$	NSS (or NWH) $H_s = E\,[H_s \mid V_{hub}]$	COD, UNI	NCM	MSL		U	N
	1.6a	NTM $V_{in} < V_{hub} < V_{out}$	SSS $H_s = H_{s,SSS}$	COD, UNI	NCM	NWLR		U	N
	1.6b	NTM $V_{in} < V_{hub} < V_{out}$	SWH $H = H_{SWH}$	COD, UNI	NCM	NWLR		U	N

Table 1 – Design Load Cases *(continued)*

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
2.x Power production plus occurrence of fault	**2.1**	NTM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL	Control system fault or loss of electrical network	U	N
	2.2	NTM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL	Protection system or preceding internal electrical fault	U	A
	2.3	EOG $V_{hub} = V_r \pm 2$ m/s and V_{out}	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL	External or internal electrical fault including loss of electrical network	U	A
	2.4	NTM $V_{in} < V_{hub} < V_{out}$	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	No currents	NWLR or ≥ MSL	Control, protection, or electrical system faults including loss of electrical network	F	*
3.x Start up	**3.1**	NWP $V_{in} < V_{hub} < V_{out}$	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	COD, UNI	No currents	NWLR or ≥ MSL		F	*
	3.2	EOG $V_{hub} = V_{in}$, $V_r \pm 2$ m/s and V_{out}	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	N
	3.3	EDC_1 $V_{hub} = V_{in}$, $V_r \pm 2$m/s and V_{out}	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	MIS, wind direction change	NCM	MSL		U	N

Table 1– Design Load Cases *(continued)*

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
4.x Normal shut down	**4.1**	NWP $V_{in} < V_{hub} < V_{out}$	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	COD, UNI	No currents	NWLR or ≥ MSL		F	*
	4.2	EOG $V_{hub} = V_r \pm$ 2m/s and V_{out}	NSS (or NWH) $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	N
5.x Emergency shut down	**5.1**	NTM $V_{hub} = V_r \pm$ 2m/s and V_{out}	NSS $H_s = E[H_s \| V_{hub}]$	COD, UNI	NCM	MSL		U	N
6.x Parked (standing still or idling)	**6.1a**	EWM Turb. wind model $V_{hub} = k_1 V_{ref}$	ESS $H_s = k_2 H_{s50}$	MIS, MUL	ECM	EWLR		U	N
	6.1b	EWM Steady wind model $V(z_{hub}) = V_{e50}$	RWH $H = H_{red50}$	MIS, MUL	ECM	EWLR		U	N
	6.1c	RWM Steady wind model $V(z_{hub}) = V_{red50}$	EWH $H = H_{50}$	MIS, MUL	ECM	EWLR		U	N
	6.2a	EWM Turb. wind model $V_{hub} = k_1 V_{ref}$	ESS $H_s = k_2 H_{s50}$	MIS, MUL	ECM	EWLR	Loss of electrical network	U	A
	6.2b	EWM Steady wind model $V(z_{hub}) = V_{e50}$	RWH $H = H_{red50}$	MIS, MUL	ECM	EWLR	Loss of electrical network	U	A
	6.3a	EWM Turb. wind model $V_{hub} = k_1 V_1$	ESS $H_s = k_2 H_{s1}$	MIS, MUL	ECM	NWLR	Extreme yaw misalignment	U	N
	6.3b	EWM Steady wind model $V(z_{hub}) = V_{e1}$	RWH $H = H_{red1}$	MIS, MUL	ECM	NWLR	Extreme yaw misalignment	U	N
	6.4	NTM $V_{hub} < 0.7 V_{ref}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*

Table 1– Design Load Cases *(continued)*

Design situation	DLC	Wind condition	Waves	Wind and wave directionality	Sea currents	Water level	Other conditions	Type of analysis	Partial safety factor
7.x Parked and fault conditions	**7.1a**	EWM Turb. wind model $V_{hub} = k_1 V_1$	ESS $H_s = k_2 H_{s1}$	MIS, MUL	ECM	NWLR		U	A
	7.1b	EWM Steady wind model $V(z_{hub}) = V_{e1}$	RWH $H = H_{red1}$	MIS, MUL	ECM	NWLR		U	A
	7.1c	RWM Steady wind model $V(z_{hub}) = V_{red1}$	EWH $H = H_1$	MIS, MUL	ECM	NWLR		U	A
	7.2	NTM $V_{hub} < 0.7\ V_l$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL		F	*
8.x Transport, assembly, maintenance and repair	**8.1**	To be stated by the manufacturer						U	T
	8.2a	EWM Turb. wind model $V_{hub} = k_1 V_1$	ESS $H_s = k_2 H_{s1}$	COD, UNI	ECM	NWLR		U	A
	8.2b	EWM Steady wind model $V_{hub} = V_{e1}$	RWH $H = H_{red1}$	COD, UNI	ECM	NWLR		U	A
	8.2c	RWM Steady wind model $V(z_{hub}) = V_{red1}$	EWH $H = H_1$	COD, UNI	ECM	NWLR		U	A
	8.3	NTM $V_{hub} < 0.7\ V_{ref}$	NSS Joint prob. distribution of H_s, T_p, V_{hub}	COD, MUL	No currents	NWLR or ≥ MSL	No grid during installation period	F	*

When a wind speed range is indicated in Table 1 (*e.g.*, $V_{hub} < 0.7\ V_{ref}$ or $V_{in} < V_{hub} < V_{out}$) wind speeds leading to the most adverse condition for wind turbine design shall be considered. The range of wind speeds may be represented by a set of discrete values, with sufficient resolution to assure accuracy of the calculation. In general a resolution of 2 m/s is considered sufficient.

APPENDIX A. IEC 61400-3 Table 1 Design Load Cases (DLCs)

ABBREVIATIONS

Wind condition

ECD	Extreme coherent gust with direction change (see IEC 61400-1)
ECM	Extreme current model (see IEC 61400-3, 6.4.2.5)
EDC	Extreme direction change (see IEC 61400-1)
EOG	Extreme operating gust (see IEC 61400-1)
ESS	Extreme sea state (see IEC 61400-3, 6.4.1.5)
EWH	Extreme wave height (see IEC 61400-3, 6.4.1.6)
EWLR	Extreme water level range (see IEC61400-3, 6.4.3.2)
EWM	Extreme wind speed model (see IEC 61400-1)
EWS	Extreme wind shear (see IEC 61400-1)
V_{hub}	Hub-height 10-minute mean wind speed (applies to all V below)
V_{in}	Cut-in wind speed (e.g., 3 to 5 m/s)
V_{out}	Cut-out wind speed (e.g., 25 m/s)
$V_r \pm 2$m/s	Rated wind speed (lowest V_{hub} at which generator attains maximum rated output)
V_{ref}	Reference wind speed (e.g. 50 m/s for Class I turbine)
MSL	Mean sea level (see IEC 61400-3, 6.4.3)
NCM	Normal current model (see IEC 61400-3, 6.4.2.4)
NTM	Normal turbulence model (see IEC 61400-1)
NWH	Normal wave height (see IEC 61400-3, 6.4.1.2)
NWLR	Normal water level range (see IEC 61400-3, 6.4.3.1)
NWP	Normal wind profile model (see IEC 61400-1)
NSS	Normal sea state (see IEC 61400-3, 6.4.1.1)
RWH	Reduced wave height (see IEC 61400-3, 6.4.1.7)
RWM	Reduced wind speed model (see IEC 61400-3, 6.3)
SSS	Severe sea state (see IEC 61400-3, 6.4.1.3)
SWH	Severe wave height (see IEC 61400-3, 6.4.1.4)

Wind and wave directionality

COD	Co-directional (see IEC 61400-3, 6.4.1)
MIS	Misaligned (see IEC 61400-3, 6.4.1)
MUL	Multi-directional (see IEC 61400-3, 6.4.1)
UNI	Uni-directional (see IEC 61400-3, 6.4.1)

Type of analysis

F	Fatigue (see IEC 61400-3, 7.6.3)
U	Ultimate strength (see IEC 61400-3, 7.6.2)

Partial safety factor

N	Normal
A	Abnormal
T	Transport and erection
*	Partial safety factor for fatigue (see IEC 61400-3, 7.6.3)