JCM Proposed Methodology Form

Cover sheet of the Proposed Methodology Form

Form for submitting the proposed methodology

Host Country	The Kingdom of Thailand
Name of the methodology proponents submitting this form	Hitachi, Ltd.
Sectoral scope(s) to which the Proposed Methodology applies	2. Energy distribution
Title of the proposed methodology, and version number	Low-carbon Operation for Power Grid Utilizing Online Voltage-var(Q) Optimal Control with ICT, Version 01.0
List of documents to be attached to this form (please check):	☐The attached draft JCM-PDD: ☒Additional information Steps to confirm validity of calculation method of reference emissions
Date of completion	10/08/2021

History of the proposed methodology

Version	Date	Contents revised
01.0	10/08/2021	First edition

A. Title of the methodology

Low-carbon Operation for Power Grid Utilizing Online Voltage-var(Q) Optimal Control with ICT, Version 01.0

B. Terms and definitions

Terms	Definitions
OPENVQ	OPENVQ stands for Optimized Performance Enabling Network for Volt-var (Q). OPENVQ is a software typically installed in power grid control rooms that collects data of transmission system online, forecasts the future system condition, automatically calculates optimum voltage control profile, and controls voltage and reactive power remotely after verifying the stability of the transmission system.

C. Summary of the methodology

Items	Summary
GHG emission reduction measures	This methodology applies to projects that aim at reducing transmission loss by optimizing voltage and reactive power of transmission system by introducing OPENVQ.
Calculation of reference emissions	Reference emissions are GHG emissions attributed to transmission loss calculated on the basis of historical voltage profile, historical reactive power profile, and condition of transmission system after implementation of the project. Transmission loss is calculated by the calculation formula based on electric circuit theory, which is adopted by Electricity Generating Authority of Thailand (EGAT). Voltage profile of reference scenario is determined by the mode value calculated from an analysis of distribution of the historical voltage measured during a period of at least one year prior to the period not earlier than 6 months before starting operation of the

	project. Reactive power of reference scenario is determined based on the reference voltage profile and active power of transmission line measured after implementation of the project.
Calculation of project emissions	Project emissions are calculated on the basis of transmission loss calculated from the monitored values using the formula based on electric circuit theory, which is adopted by EGAT.
Monitoring parameters	Active power, reactive power, voltage, resistance, reactance, susceptance of the transmission line, and the number of transmission lines in the project area X.

D. Eligibility criteria

This methodology is applicable to projects that satisfy all of the following criteria.

Criterion 1	The project installs OPENVQ to the control system of transmission network.
Criterion 2	The project transmission network is one of the five regional networks served by EGAT, in which each network is controlled by respective regional control center (RCC). The project transmission network has delivery points which are connected to the regional distribution network corresponding to each of the five regions managed by Metropolitan Electricity Authority (MEA), and four Provincial Electricity Authorities (PEA), Northeast, South, North, and Central, respectively. The project transmission network consists of transmission lines of 500kV, 230kV, and 115kV, and substations.
Criterion 3	The project transmission network is monitored and operated on-line, and the data of active power, reactive power, voltage, resistance, and susceptance of the transmission line is collected remotely.
Criterion 4	The difference between reference transmission line loss calculated based on the procedure described in F.2 and calculated transmission line loss based on the data measured during sampling period is less than the difference between measured substation loss and simulated substation loss in the case of installing OPENVQ based on the data measured during sampling period. This is confirmed by satisfying the following formula: $$PL_{RE,X,lines} - PL_{measured,X,lines} < PL_{measured,X,substations} - PL_{OPENVQ,X,substations}$$ $PL_{RE,X,lines}$ = Reference transmission line loss (W) $PL_{measured,X,lines}$ = Measured transmission line loss in the

	sampling period (W) $PL_{measured,X,substations}$ = Measured substation loss in the sampling period (W) $PL_{OPENVQ,X,substations}$ = Simulated substation loss in the case of installing OPENVQ (W) The detail steps to confirm validity of calculation method of reference emissions are described in Additional Information.

E. Emission Sources and GHG types

Reference emissions	
Emission sources	GHG types
Transmission loss of transmission line	CO_2
Project emissions	
Emission sources	GHG types
Transmission loss of transmission line	CO_2

F. Establishment and calculation of reference emissions

F.1. Establishment of reference emissions

By introduction of OPENVQ, transmission loss is reduced by optimizing voltage and reactive power of transmission system. Reference emissions attributed to reference transmission loss are calculated on the basis of historical voltage profile, historical reactive power profile, and condition of transmission network after implementation of the project. Transmission loss of transmission line i (PL_{line_i}) which connects bus k and bus l is calculated by the calculation formula of EGAT:

$$PL_{line_i} = P_{k,i} + \tilde{P}_i$$
$$\equiv f(P_{k,i}, Q_{k,i}, V_{k,i}, V_{l,i}, R_i, X_i, B_i),$$

and intermediate formula is shown as below:

$$\tilde{P}_i = \tilde{V}_l Y_i \cdot \cos\theta - V_{k,i} \cdot \tilde{V}_l Y_i \cdot \cos(\theta - \tilde{\theta})$$
$$\tilde{V}_l = \frac{V_{k,i}^2 \cdot Y_i \cdot \cos\theta - P_{k,i}}{V_{k,i} \cdot Y_i \cdot \cos(\theta + \tilde{\theta})}$$

$$Y_i = \frac{1}{\sqrt{R_i^2 + X_i^2}}$$

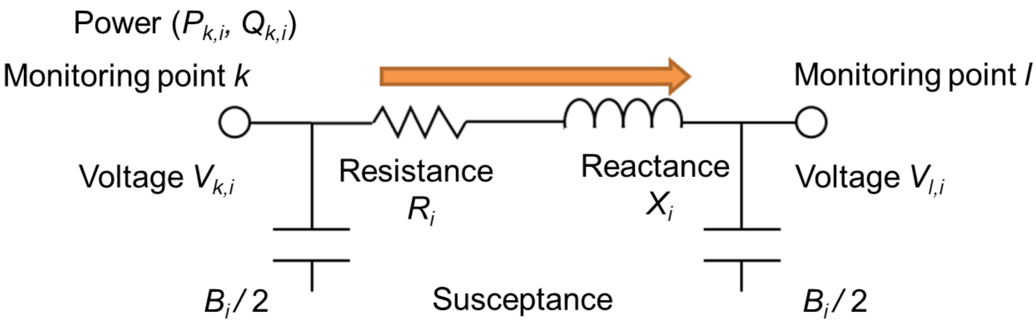
$$\theta = -\tan^{-1}\frac{X_i}{R_i}$$

$$\tilde{\theta} = -\theta + \tan^{-1}\left(\frac{Q_{k,i}+V_{k,i}^2 \cdot Y_i \cdot \sin\theta + V_{k,i}^2 \cdot B_i/2}{V_{k,i}^2 \cdot Y_i \cdot \cos\theta - P_{k,i}}\right).$$

Where

PL_{line_i}	=	Transmission loss of transmission line i (W)
$P_{k,i}$	=	Active power at the bus k of transmission line i (W)
$Q_{k,i}$	=	Reactive power at the bus k of transmission line i (var)
$V_{k,i}$	=	Voltage measured at the bus k of transmission line i (V)
$V_{l,i}$	=	Voltage measured at the bus l of transmission line i (V)
Y_i	=	Admittance of transmission line i (S)
R_i	=	Resistance of transmission line i (Ω)
X_i	=	Reactance of transmission line i (Ω)
B_i	=	Susceptance of transmission line i (S)

Each parameter of transmission line i which connects bus k and bus l shows value described in the figure below:



Reference voltage profile is determined by identifying the mode value of the historical voltage of each transmission line. Mode value is calculated through analysis of histogram representing a distribution of the ratio of historical voltage to the base voltage. The historical voltage is measured for at least one year before implementation of the project. Reference voltage is determined by multiplying mode value of the ratio by the base voltage of each transmission line per transmission capacity.

Reactive power is derived by equation based on voltage profile, active power, and condition of transmission system, as determined by resistance, reactance, and susceptance. Therefore, reactive power of reference scenario is determined based on the reference voltage profile, active power of transmission line measured after implementation of the project, and condition of transmission system after implementation of the project.

Ensuring net emission reduction

Through the introduction of OPENVQ, loss at the transmission lines and substations in the project network is expected to be reduced. The methodology ensures net emission reduction by not taking into account reduction of electricity consumption attributed to reduction of loss at the substations in the project network which occurs as a result of introduction of OPENVQ.

F.2. Calculation of reference emissions

$$RE_p = PL_{RE,X,lines,p} \times EF_{Grid} \quad (1)$$

Where

RE_p	=	Reference emission during the period p (tCO_2/p)
$PL_{RE,X,lines,p}$	=	Reference transmission line loss at transmission lines in the project area X during the period p (MWh/p)
EF_{Grid}	=	CO_2 emission factor for grid (tCO_2/MWh)

$$PL_{RE,X,lines,p} = \sum_{i=1}^{N} PL_{RE,line_i,p} \quad (2)$$

Where

$PL_{RE,line_i,p}$	=	Reference transmission line loss at transmission line i during the period p (MWh/p)
N	=	Number of transmission lines in the project area X (-)

$$PL_{RE,line_i,p} = \sum_{t=0}^{p} PL_{RE,line_i,t} \times \frac{T}{60} \times 10^{-6} \quad (3)$$

Where

$PL_{RE,line_i,t}$	=	Reference transmission line loss at transmission line i at the time t (W)
T	=	Measurement interval (min) (Fixed *ex ante*)

$PL_{RE,line_i,t}$ is calculated based on the calculation formula of EGAT as follows.

$$PL_{RE,line_i,t} = f(P_{k,i,t}, Q_{RE,k,i,t}, V_{RE,k,i}, V_{RE,l,i,t}, R_i, X_i, B_i) \quad (4)$$

Where

$P_{k,i,t}$	=	Active power at the bus k of transmission line i at the time t (W)

		(monitored)
$Q_{RE,k,i,t}$	=	Reference reactive power at the bus k of transmission line i at the time t (var) (calculated)
$V_{RE,k,i}$	=	Reference voltage at the bus k of transmission line i (V) (calculated)
$V_{RE,l,i,t}$	=	Reference voltage at the bus l of transmission line i at the time t (V) (calculated)
R_i	=	Resistance of transmission line i (Ω) (Fixed *ex ante)*
X_i	=	Reactance of transmission line i (Ω) (Fixed *ex ante*)
B_i	=	Susceptance of transmission line i (S) (Fixed *ex ante*)

Since active power will not be affected by the introduction of OPENVQ, active power measured during the project period $P_{k,i,t}$ is used to represent active power of reference scenario.

R_i, X_i, B_i, are parameters related to the specification of the transmission lines. The measured value during the project period is used to represent the project transmission line.

Reference voltage $V_{RE,k,i}$, $V_{RE,l,i,t}$, and reference reactive power $Q_{RE,k,i,t}$ are derived by the following steps:

Step 1: Obtain voltage data $V_{k,i}$ (V) measured at bus k for each transmission line i which connects bus k and bus l in the project area for a certain day of each month for one year set at regular interval (total at least 12 days) prior to the period not earlier than 6 months before starting operation of OPENVQ.

Step 2: Calculate the ratio of $V_{k,i}$ to the base voltage $V_{base,i}$ (V) of transmission line i. The base voltage $V_{base,i}$ is the rated voltage of buses which are connected by transmission line i.

$$Ratio_k = \frac{V_{k,i}}{V_{base,i}} \quad (5)$$

Step 3: Plot all obtained values of $Ratio_k$, (-) for all transmission lines in the project area with an interval of 0.01 which can be demonstrated in the form of a histogram.

Step 4: Select the most frequently observed value of $Ratio_{mode}$ (-).

Step 5: Calculate reference voltage $V_{RE,k,i}$ by multiplying $Ratio_{mode}$ by the base voltage $V_{base,i}$ of transmission line i.

$$V_{RE,k,i} = Ratio_{mode} \cdot V_{base,i} \quad (6)$$

Step 6: Reference voltage at bus l is calculated as a function of $V_{RE,k,i}$.

$$V_{RE,l,i,t} = V_{RE,k,i} - X_i \cdot Q_{k,i,t} \quad (7)$$

Where

$Q_{k,i,t}$ = Reactive power at the bus k of transmission line i at the time t (var) (monitored)

Step 7:

Reference reactive power ($Q_{RE,k,i,t}$) is derived by the following equations:

$$Q_{RE,k,i,t} = Y_i \cdot V_{RE,k,i}^2 \cdot sin\,\phi - Y_i \cdot V_{RE,k,i} \cdot V_{RE,l,i,t} \cdot sin(\delta + \phi) - \frac{B_i}{2} \cdot V_{RE,k,i}^2 \quad (8)$$

$$\delta = sin^{-1}\frac{X_i \cdot P_{k,i,t}}{V_{RE,k,i} \cdot V_{l,i,t}} \quad (9)$$

$$\phi = \tan^{-1}\frac{X_i}{R_i} \quad (10)$$

$$Y_i = \frac{1}{\sqrt{R_i^2 + X_i^2}} \quad (11)$$

Where

$Q_{RE,k,i,t}$ = Reference reactive power at the bus k of transmission line i at the time t (var) (calculated)

Y_i = Admittance of transmission line i (S)

$V_{RE,k,i}$ = Reference voltage at the bus k of transmission line i (V) (calculated)

$V_{RE,l,i,t}$ = Reference voltage at the bus l of transmission line i at the time t (V) (calculated)

ϕ = Impedance angle (rad) (calculated)

δ = Phase angle (rad) (calculated)

$V_{l,i,t}$ = Voltage measured at the bus l of transmission line i at the time t (V) (monitored)

$P_{k,i,t}$ = Active power at the bus k of transmission line i at the time t (W) (monitored)

R_i = Resistance of transmission line i (Ω) (Fixed *ex ante)*

X_i = Reactance of transmission line i (Ω) (Fixed *ex ante*)

B_i = Susceptance of transmission line i (S) (Fixed *ex ante*)

G. Calculation of project emissions

$$PE_p = PL_{PJ,X,lines,p} \times EF_{Grid} \tag{12}$$

$$PL_{PJ,X,lines,p} = \sum_{i=1}^{N} PL_{PJ,line_i,p} \tag{13}$$

Where

PE_p	=	Project emission during the period p (tCO_2/p)
$PL_{PJ,X,lines,p}$	=	Project transmission line loss at transmission lines in the project area X during the period p (MWh/p)
EF_{Grid}	=	CO_2 emission factor for grid（tCO_2/MWh）
$PL_{PJ,line_i,p}$	=	Project transmission line loss at transmission line i during the period p (MWh/p)
N	=	Number of transmission lines in the project area X (-)

$$PL_{PJ,line_i,p} = \sum_{t=0}^{p} PL_{PJ,line_i,t} \times \frac{T}{60} \times 10^{-6} \tag{14}$$

Where

$PL_{PJ,line_i,t}$	=	Project transmission line loss at transmission line i at the time t (W)
T	=	Measurement interval (min)

$PL_{PJ,line_i,t}$ is calculated based on the calculation formula of EGAT as follows:

$$PL_{PJ,line_i,t} = f(P_{k,i,t}, Q_{k,i,t}, V_{k,i,t}, V_{l,i,t}, R_i, X_i, B_i) \tag{15}$$

Where

$P_{k,i,t}$	=	Active power at the bus k of transmission line i at the time t (W) (monitored)
$Q_{k,i,t}$	=	Reactive power at the bus k of transmission line i at the time t (var) (monitored)
$V_{k,i,t}$	=	Voltage measured at the bus k of transmission line i at the time t (V) (monitored)
$V_{l,i,t}$	=	Voltage measured at the bus l of transmission line i at the time t (V) (monitored)
R_i	=	Resistance of transmission line i (Ω) (Fixed *ex ante*)
X_i	=	Reactance of transmission line i (Ω) (Fixed *ex ante*)
B_i	=	Susceptance of transmission line i (S) (Fixed *ex ante*)

H. Calculation of emissions reductions

$$ER_p = RE_p - PE_p \quad (16)$$

Where

ER_p = Emission reduction during the period p (tCO_2/p)
RE_p = Reference emission during the period p (tCO_2/p)
PE_p = Project emission during the period p (tCO_2/p)

I. Data and parameters fixed *ex ante*

The source of each data and parameter fixed *ex ante* is listed as below.

Parameter	Description of data	Source
EF_{Grid}	CO_2 emission factor for grid (tCO_2/MWh)	**[Grid electricity]** The most recent value available at the time of validation is applied and fixed for the monitoring period thereafter. The data is sourced from "Grid Emission Factor (GEF) of Thailand", endorsed by Thailand Greenhouse Gas Management Organization, unless otherwise instructed by the Joint Committee.
$Ratio_{mode}$	Mode value of $Ratio_k$ of $V_{k,i}$ to the base voltage $V_{base,i}$ of transmission line i (-)	Calculated based on the procedure described in F.2.
R_i	Resistance of transmission line i (Ω)	The constant value of equivalent circuit which represents the condition of transmission line i.
X_i	Reactance of transmission line i (Ω)	The constant value of equivalent circuit which represents the condition of transmission line i.
B_i	Susceptance of transmission line i (S)	The constant value of equivalent circuit which represents the condition of transmission line i.
T	Measurement interval (min)	Predetermined measurement interval

$V_{base,i}$	Base voltage of transmission line *i* (V)	Specification of transmission line *i*
$V_{RE,k,i}$	Reference voltage at the bus *k* of transmission line *i*	Calculated based on the procedure described in F.2.