**Joint Crediting Mechanism Approved Methodology TH_AM017**
**"Low-carbon Operation for Power Grid Utilizing Online Voltage-var(Q) Optimal Control with ICT"**

## A. Title of the methodology

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| 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).<br>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 introducing OPENVQ and optimizing voltage and reactive power of transmission system. |
| *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 |

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|---|---|
| | Generating Authority of Thailand (EGAT). Reference voltage profile 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. Reference reactive power 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 are measured. Reference/project transmission line loss, reference reactive power and reference voltage are calculated and monitored in OPENVQ system based on the measured parameters. |

## D. Eligibility criteria

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

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|---|---|
| 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:<br><br>$$PL_{RE,X,lines} - PL_{measured,X,lines} < PL_{measured,X,substations} - PL_{OPENVQ,X,substations}$$<br><br>$PL_{RE,X,lines}$ = Reference transmission line loss (W)<br>$PL_{measured,X,lines}$ = Measured transmission line loss in the sampling period (W)<br>$PL_{measured,X,substations}$ = Measured substation loss in the sampling period (W)<br>$PL_{OPENVQ,X,substations}$ = Simulated substation loss in the case of installing OPENVQ (W)<br>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:

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

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

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

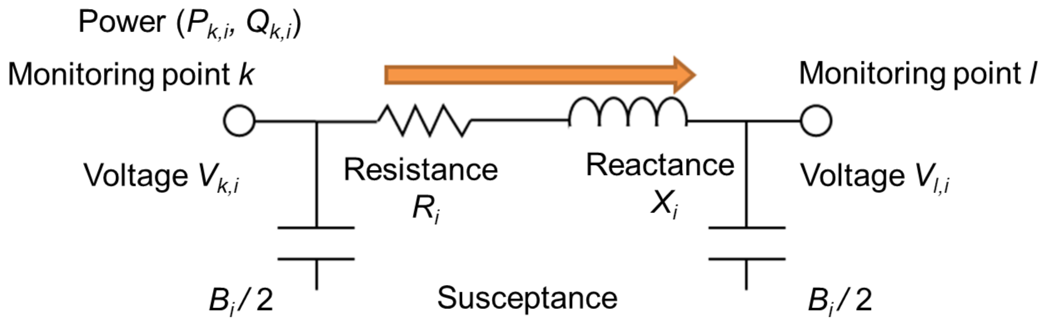
$$\theta = -\tan^{-1}\frac{X_i}{R_i}$$

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

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 a value described in the figure below:



A reference voltage profile is determined by identifying the mode value of the historical voltage of each transmission line. The 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 the mode value of the ratio by the base voltage of each transmission line per transmission capacity.
Reactive power is derived by equation based on a voltage profile, active power and condition of transmission system, as determined by resistance, reactance and susceptance. Therefore, reference reactive power 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**

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

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)

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

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 $X$ (-)

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

Where

$PL_{RE,line_i,t}$ = Reference transmission line loss at transmission line $i$ at the time $t$ (W)

$T$ = Measurement interval (min)

$PL_{RE,line_i,t}$ is calculated based on the calculation formula of EGAT, which is described in Section F.1.

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

Where

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

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

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

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

$R_i$ = Resistance of transmission line $i$ (Ω)

$X_i$ = Reactance of transmission line $i$ (Ω)

$B_i$ = Susceptance of transmission line $i$ (S)

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 reference active power.
$R_i$, $X_i$, $B_i$, are parameters related to the specification of the transmission lines. The values are calculated based on the configuration characteristics of transmission line $i$ at the time of validation. 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 $i$.

$$V_{RE,k,i} = Ratio_{mode} \cdot V_{base,i} \tag{6}$$

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

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

Where

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

Step 7:

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

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

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

$$\phi = \tan^{-1} \frac{X_i}{R_i} \tag{10}$$

$$Y_i = \frac{1}{\sqrt{R_i^2 + X_i^2}} \tag{11}$$

Where

| | | |
|---|---|---|
| $Q_{RE,k,i,t}$ | = | Reference reactive power at the bus $k$ of transmission line $i$ at the time $t$ (var) |
| $Y_i$ | = | Admittance of transmission line $i$ (S) |
| $V_{REk,i}$ | = | Reference voltage at the bus $k$ of transmission line $i$ (V) |
| $V_{RE,l,i,t}$ | = | Reference voltage at the bus $l$ of transmission line $i$ at the time $t$ (V) |
| $\phi$ | = | Impedance angle (rad) |
| $\delta$ | = | Phase angle (rad) |
| $V_{l,i,t}$ | = | Voltage measured at the bus $l$ of transmission line $i$ at the time $t$ (V) |
| $P_{k,i,t}$ | = | Active power at the bus $k$ of transmission line $i$ at the time $t$ (W) |
| $R_i$ | = | Resistance of transmission line $i$ (Ω) |
| $X_i$ | = | Reactance of transmission line $i$ (Ω) |
| $B_i$ | = | Susceptance of transmission line $i$ (S) |

## G. Calculation of project emissions

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

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

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 $X$ (-) |

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

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:

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

Where

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

## 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) | Calculated by electromagnetics based on the configuration characteristics like tower geometry, conductor types, number, phasing and ground condition of circuits of overhead transmission line $i$ which are obtained from EGAT. The calculations are performed using a general-purpose calculation program package. |

| | | |
|---|---|---|
| $X_i$ | Reactance of transmission line *i* (Ω) | Calculated by electromagnetics based on the configuration characteristics like tower geometry, conductor types, number, phasing and ground condition of circuits of overhead transmission line *i* which are obtained from EGAT. The calculations are performed using a general-purpose calculation program package. |
| $B_i$ | Susceptance of transmission line *i* (S) | Calculated by electromagnetics based on the configuration characteristics like tower geometry, conductor types, number, phasing and ground condition of circuits of overhead transmission line *i* which are obtained from EGAT. The calculations are performed using a general-purpose calculation program package. |
| $T$ | 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* (V) | Calculated based on the procedure described in F.2. |

History of the document

| Version | Date | Contents revised |
|---|---|---|
| 01.0 | 17 June 2022 | Electronic decision by the Joint Committee<br>Initial approval. |
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