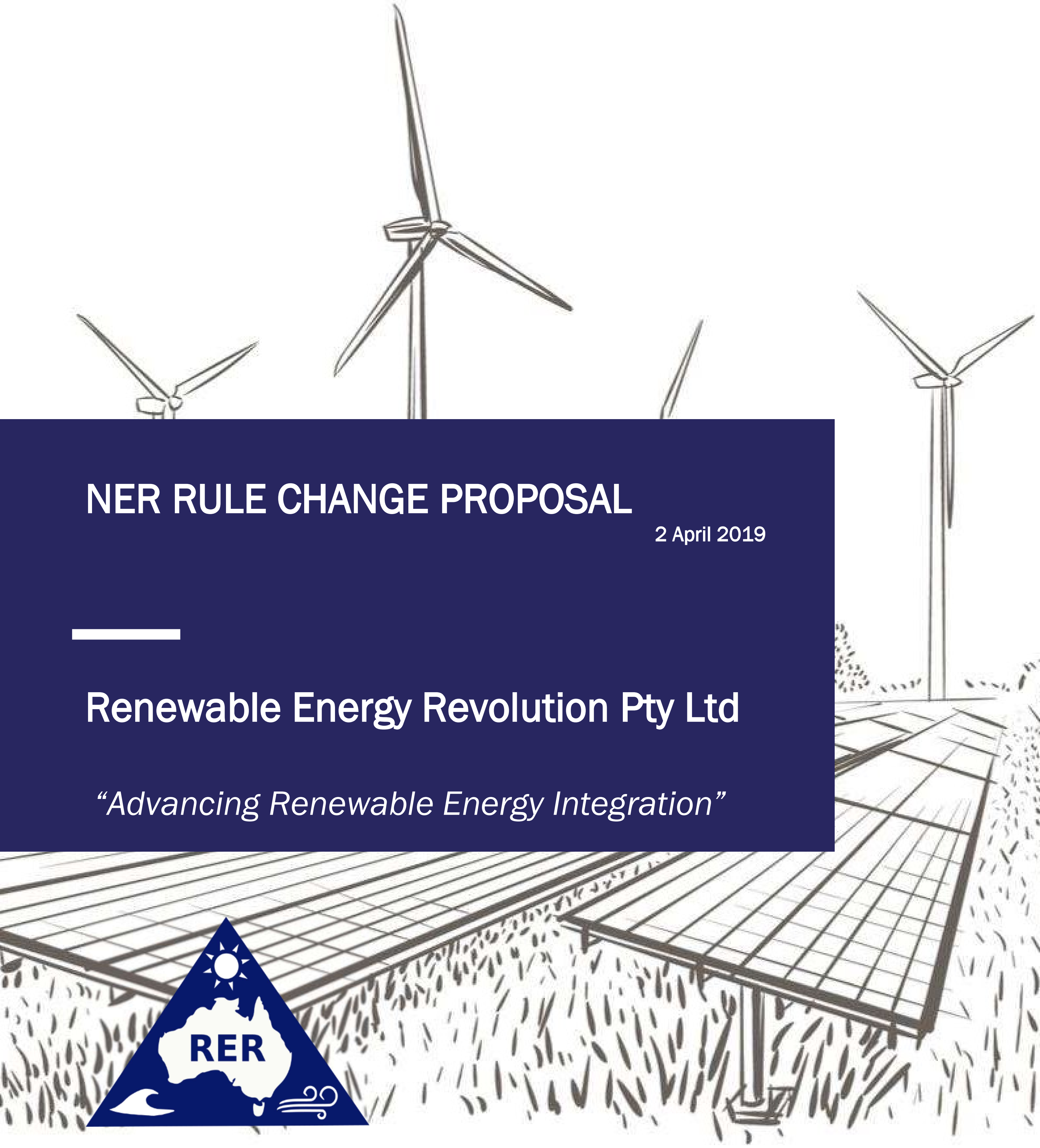

NER RULE CHANGE PROPOSAL

2 April 2019

Renewable Energy Revolution Pty Ltd

“Advancing Renewable Energy Integration”

Distribution of Document

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About Renewable Energy Revolution

Renewable Energy Revolution is the consultancy of Dr. Christopher Rowe, who has designed and assessed over 1.5 GW of renewable energy under the Australian NER.

Name of person making the request:

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This rule change request has taken months of unpaid work. The aim is to improve the control of renewable energy in the Australian grid.

Description of rule to be changed

The maximum reactive current value would be changed to correctly align the frame of voltage control (voltage support) in remote / weak grids (low X/R grids).

The exact rule to be changed is located on Page 655 of the National Electricity Rules (NER) Version 119, extracted here for convenience:

"(u) For the purpose of paragraphs (f) and (n):

(1) the reactive current contribution may be limited to the maximum continuous current of a generating system, including its operating asynchronous generating units;"

A statement of the nature and scope of the issue concerning the existing rules that is to be addressed by the proposed rule change request

The current rule, by demanding 100% current, aligns the voltage support mechanism entirely with the Q-axis.

In a low X/R grid there is the need to compensate for the considerable voltage drop across the resistive network impedance. This can be achieved by limiting the maximum reactive current, and thus supplying active current, in a Q priority inverter. Q priority is used in most inverters installed in Registered Generating systems in the Australian Grid.

The current rule, by demanding 100% ‘maximum reactive current’, forces the alignment of the voltage support mechanism entirely with the Q-axis. Further, it allows no concession to reduce this value. Note that where the control is incorrectly aligned, generally, the inverters achievable performance will be degraded.

It is worthy to note that generally the generator has already satisfied S5.2.5.1 and S5.2.5.4. Note that ‘maximum reactive current’ relates to the hardware capabilities and has no tangible link to the S5.2.5.1 (0.395 * Pmax requirement at low voltage), or to the S5.2.5.4 requirement.

The S5.2.5.1 and S5.2.5.4 requirements normally dictate the MVA size of a Solar or Wind generator. In this document it is suggested that where a generator has satisfied S5.2.5.1 and S5.2.5.4*, and the generator is sized correctly*.

After this we must decide how to control the unit. This document suggests the control should be correctly aligned with the local POC characteristics (X/R ratio). As the inverter control is implemented in the positive sequence domain, and the iq tables referred to occur in the positive sequence domain, this discussion should be viewed in the positive sequence domain of converter control.

An explanation of how the proposed rule change request would address the issue

This rule change facilitates the correct alignment of the voltage support mechanism during faults, where the point of connection has a low X/R ratio.

An explanation of how the proposed rule change request will or is likely to contribute to the achievement of the relevant energy objective

This rule change proposal is directly aligned with achieving Australia’s national electricity objective:

> *“to promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to:*
>
> *price, quality, safety and reliability and security of supply of electricity*
> *the reliability, safety and security of the national electricity system."*

Specifically, the terms:

1. efficient operation and use of,
2. price, and
3. quality.

Without the construction of additional transmission line infrastructure, the transition to a cheaper electricity price in Australia requires a large number of generators to be constructed on the 132kV and 66kV networks. This is so that the generators are distributed in harvesting energy, while not too concentrated to overload the existing network.

This rule change facilitates the construction of these generators by:

1. Correctly aligning the voltage support mechanism during faults.
2. Allowing improved control performance by achieving (1).
3. Improved control action may increase the allowable MW per point of connection (density of power per POC), considering currently observed dynamic limitations.

An explanation of the expected potential impacts of the proposed change to the rules on those likely to be affected

Solar and (Full Converter) Wind Generators are expected to be affected, and to see improved control in low X/R ratio grids. No additional cost will be incurred, by any parties, under the proposed wording.

The new rule would allow applicants to limit the maximum reactive current (iq) to 92.85% - 99.23% of the current rating of the generating unit. Note that the maximum continuous current of the converter is still provided (100%), however the angle of the current is changed to benefit the grid.

The inverter (or full converter) would remain operated in a Q priority mode and only a minor change made to the inverter diqdv table.

Example of impact of change

Figure 1 - X/R =3 site, diQdv settings under current rules. Settings points: [0.85, 0], [0.6,1], [0, 1]

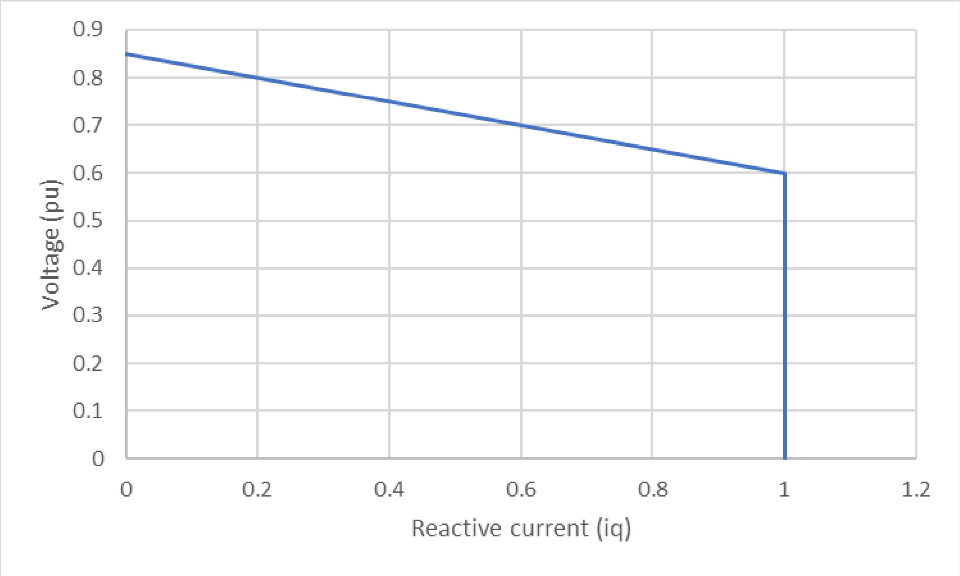
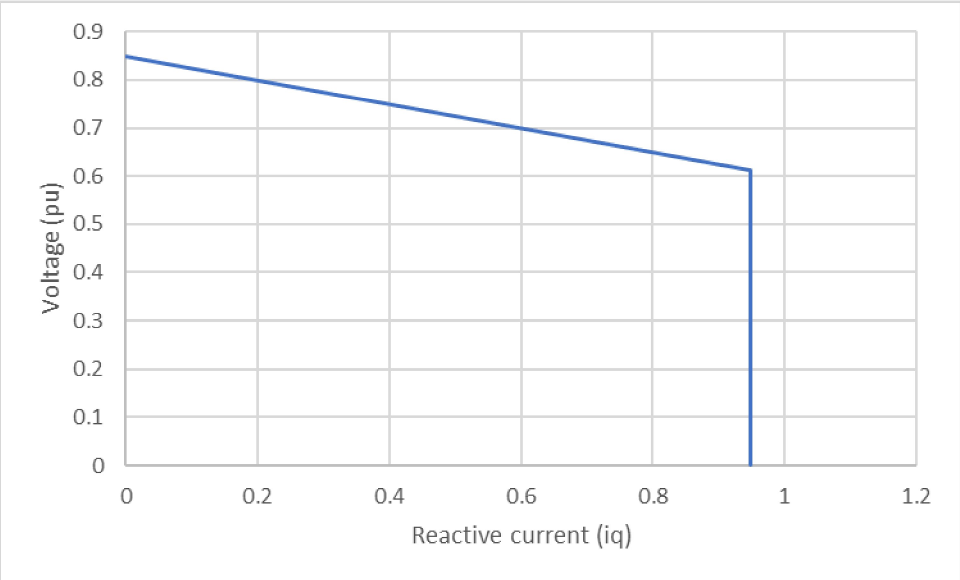


Figure 2 - X/R =3 site, diQdv settings under new proposed wording. Settings points: [0.85, 0], [0.6128,0.9487], [0, 0.9487]



Notes on Protection

The protection could be affected. Protection experts should be consulted. However, a quick analysis here. Over current relays act on current magnitude which remains 100%, should be unaffected. Distance relays act on current vs voltage, now the current magnitude is better aligned to the voltage and the current magnitude is 100%. Expected outcome is equivalent or improved performance, locally.

Proposed new wording

"(u) For the purpose of paragraphs (f) and (n):
(1) the *reactive current contribution* may be limited to:

(a) the *maximum continuous current* of a *generating system*, including its operating asynchronous *generating units*, or

(b) the current listed in Table A, for the *Half-Integer X/R Ratio* at the *generating units* point of connection, where the *generating system* contributes the *maximum continuous current* of the *generating system*, as active and reactive current, including its operating asynchronous *generating units*;"

Proposed New Term (1)

Half-Integer X/R Ratio - The reactance divided by the resistance of the network impedance observed at the point of connection of a generating system under a system normal condition, rounded to the nearest half-integer (0.5).

Proposed New Table (1)

Table A - Maximum reactive and continuous currents considering Half-Integer X/R Ratio

Half Integer X/R Ratio	Maximum reactive Current (pu)	Maximum continuous current (pu)
8.0	0.9923	1.0
7.5	0.9912	1.0
7.0	0.9899	1.0
6.5	0.9884	1.0
6.0	0.9864	1.0
5.5	0.9839	1.0
5.0	0.9806	1.0
4.5	0.9762	1.0
4.0	0.9701	1.0
3.5	0.9615	1.0
3.0	0.9487	1.0
2.5	0.9285	1.0

Conclusion

The current NER wording under Clause 5.2.5.5(u)(1), demands a level of current injection that may be deleterious to medium voltage and low voltage points of connection, due to the fact the local X/R ratio is not considered. The current NER wording may:

1. Lead to decreased voltage support during faults at MV and LV points of connection, or remote HV points of connection.
2. Degrade inverters ability to track voltage during and post fault due to an increased reactive power injection, and rapid changes in reactive power, that are above the level required by power line physics.

Examining Table A, we see that for common points of connection X/R ratio, that is 4 to 7, the existing NER wording will lead to provision of 100% reactive current and therefore the loss of much needed active current (0.2425 to 0.1414 pu) to provide voltage support in low X/R ratio sites, which are common in Australia.

Sincerely,
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Appendix A -Table A1: Explanation of resultant additional active current (id) injection due to proposed change

The below table explains quantitatively how much increase will be seen in active power with the proposed rule change. This should minimize active power transients in faults, and fault studies and may increase the allowable MW per POC.

Table A1

Half Integer X/R Ratio	Maximum Reactive Current (pu)	**Resultant Additional Active Current (pu)**	Maximum total current (pu)
8.0	0.9923	**0.124**	1.0
7.5	0.9912	**0.1322**	1.0
7.0	0.9899	**0.1414**	1.0
6.5	0.9884	**0.1521**	1.0
6.0	0.9864	**0.1644**	1.0
5.5	0.9839	**0.1789**	1.0
5.0	0.9806	**0.1961**	1.0
4.5	0.9762	**0.2169**	1.0
4.0	0.9701	**0.2425**	1.0
3.5	0.9615	**0.2747**	1.0
3.0	0.9487	**0.3162**	1.0
2.5	0.9285	**0.3714**	1.0

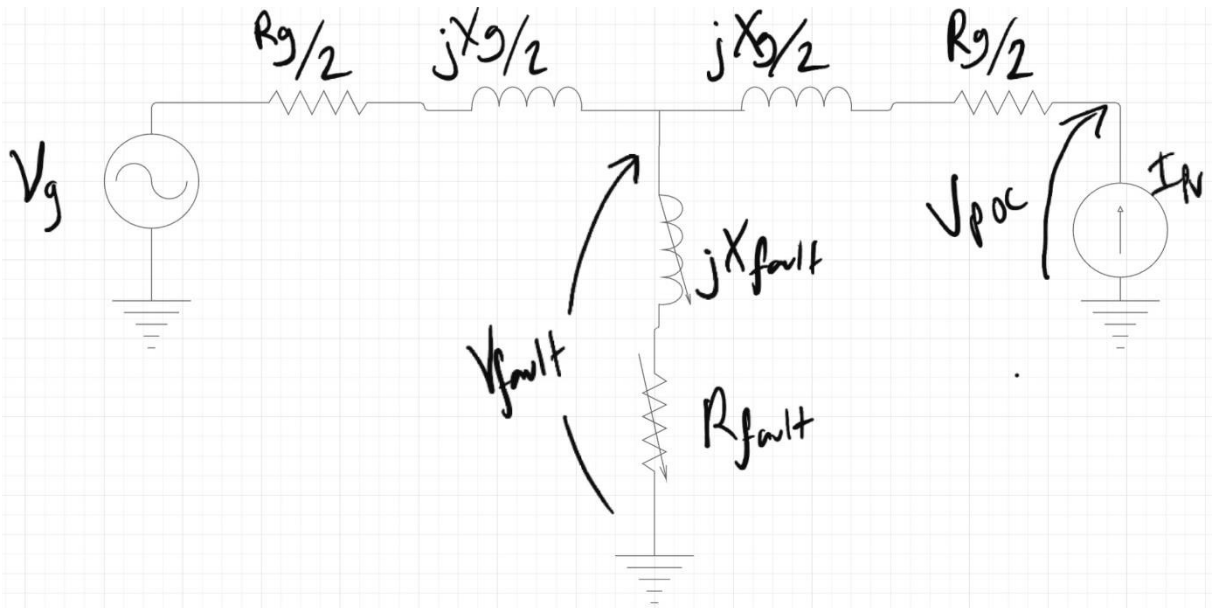
Appendix B - Theoretical Proof

THEORY 1 OF 2 - UNDERSTANDING LOCAL POC VOLTAGE CHARACTERISTICS IN A GRID DOMINATED BY DISTRIBUTED RESOURCES (A WEAK GRID).

Assumption: There is a fault in the network that occurs 50% down the abstract 'grid impedance' quantity.

Derive the i_d and i_q for maximum voltage support. Prove for all complex numbers.

Figure B1 - Local POC Voltage derivation



<u>Terms</u>

V_flt = Voltage at Fault in the dq Rotating Reference Frame
V_poc = Voltage at POC in the dq Rotating Reference Frame
R_g = Grid Resistance
X_g = Grid Reactance
R_fault = Fault Resistance
X_fault = Fault Reactance
i_d = inverter direct axis current
i_q = inverter quadrature axis current

<u>Calculations in the rotating reference frame:</u>

$V\_flt = V\_flt\_d + j\, V\_flt\_q$

$V\_poc\_d + j\, V\_poc\_q = V\_flt\_d + j\, V\_flt\_q + (i\_d + j\, i\_q)(R\_g/2 + j\, X\_g/2)$
$= V\_flt\_d + j\, V\_flt\_q + i\_d\, R\_g\,/\,2 + j\, i\_q\, R\_g\,/\,2 + j\, i\_d\, X\_g\,/\,2 - i\_q\, X\_g\,/2$

Therefore, collecting d-axis terms:
V_poc_d = V_flt_d + i_d (R_g / 2) - i_q (X_g / 2)

Thus, to support voltage in a low X/R grid we must supply both i_d (active current) and -i_q (capacitive reactive current).

The ratio of i_d / i_q current supply for maximum voltage support is given by the X/R ratio and calculated in part 2.

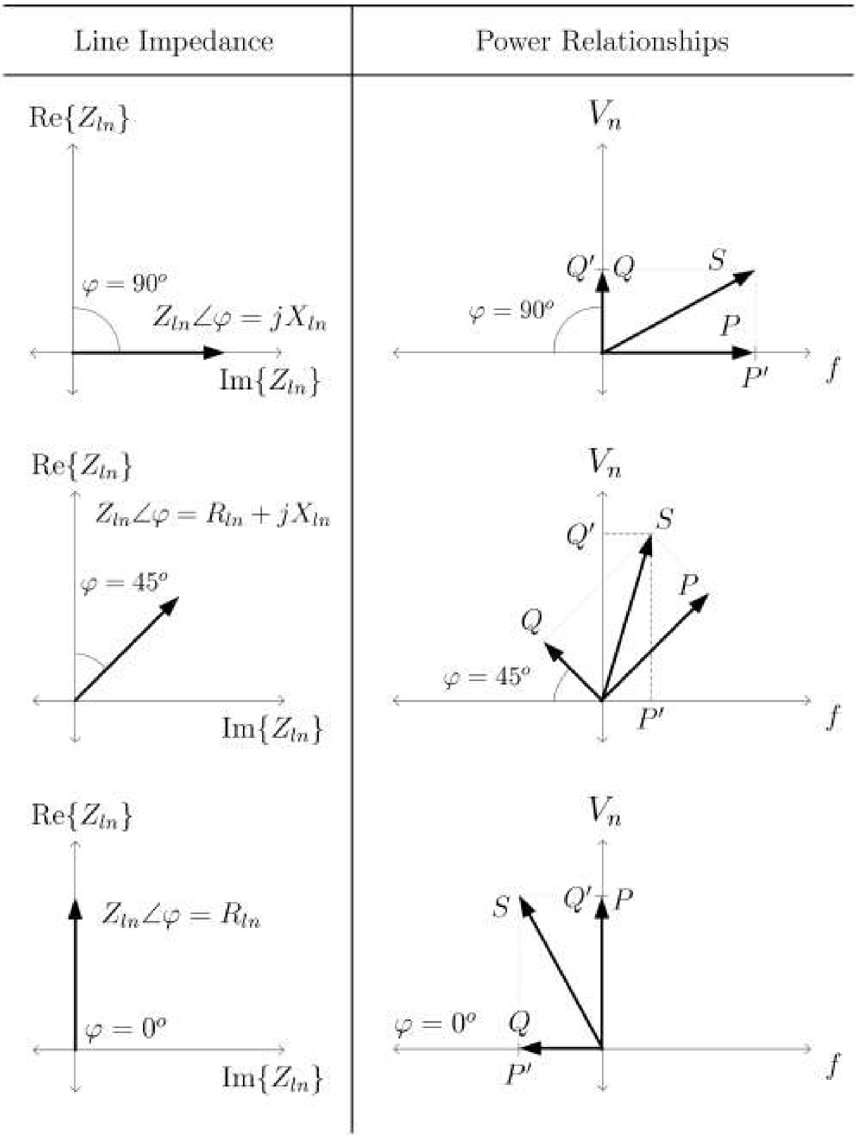
<u>Theory 2 of 2 – Calculating maximum iq based on X/R</u>

The Linear Rotation Transform was first used by De Brabandere and has been used as a staple of microgrid control theory for over 10 years. The full equation is as below:

$$\begin{bmatrix} P' \\ Q' \end{bmatrix} = T \begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} \sin\varphi & -\cos\varphi \\ \cos\varphi & \sin\varphi \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} \frac{X_{ln}}{Z_{ln}} & -\frac{R_{ln}}{Z_{ln}} \\ \frac{R_{ln}}{Z_{ln}} & \frac{X_{ln}}{Z_{ln}} \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix}$$

To control power sharing the control is directly related to the X/R ratio. In a resistive grid P controls Voltage, in an inductive grid (as the high voltage network is) we use Q to control Voltage. The below figure shows graphically this:

Figure B2 – Linear Rotational Transform



These equations are simplified to find the i_q magnitude limitation based on the X/R ratio of the POC to give the best control alignment.

Please refer to RuleChangeCalcs.xlsx for full mathematics. RAW in Excel: “=SQRT(1/(1+1/(K21^2)))”

To ensure that the current injection allows the voltage rise to be aligned with the d-axis voltage (in other words the local alignment of voltage) we wish to slightly alter the iq maximum. This then with Q priority control gives the desired outcome. The equation, once reduced and common terms eliminated becomes:

Iq magnitude limit (pu) = SQRT (1 / (1+ 1/(X_on_R^2)))

This equation is used to calculate i_q limits in Table A proposed in the rule change.