Australian Power Quality and Reliability Centre

# Rapid Voltage Changes

Technical Note 18
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UNIVERSITY OF WOLLONGONG

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# 1. Definition of Rapid Voltage Change & their Types

In simple terms a rapid voltage change (RVC) can be described as a short term variation in the root mean square (RMS) voltage ($\Delta V$) between two steady state conditions ($V_{ss1}$ and $V_{ss2}$) where the voltage does not exceed the voltage dip (sag) or the voltage swell thresholds as shown in Fig. 1 [1, 2]. Typical RVCs that can prevail in electricity networks can be classified into types (a) rectangular, (b) ramp, and (c) motor start, as illustrated in Fig. 1. Considering the impact of voltage changes on light intensity (traditionally, for incandescent light globes, light intensity is approximately proportional to voltage):

- For type (a) the visibility of the light intensity variation associated with the RVC will depend on the voltage change ($\Delta V$).
- For type (b) this visibility will depend on the duration of the voltage change and the magnitude of the voltage change itself ($\Delta t$ and $\Delta V$).
- For type (c) the visibility will depend on the initial change in the voltage ($\Delta V_{max}$), the duration of the voltage recovery to the new voltage level and the change in the voltage from the previous voltage level $V_{ss1}$ to the new level $V_{ss2}$.

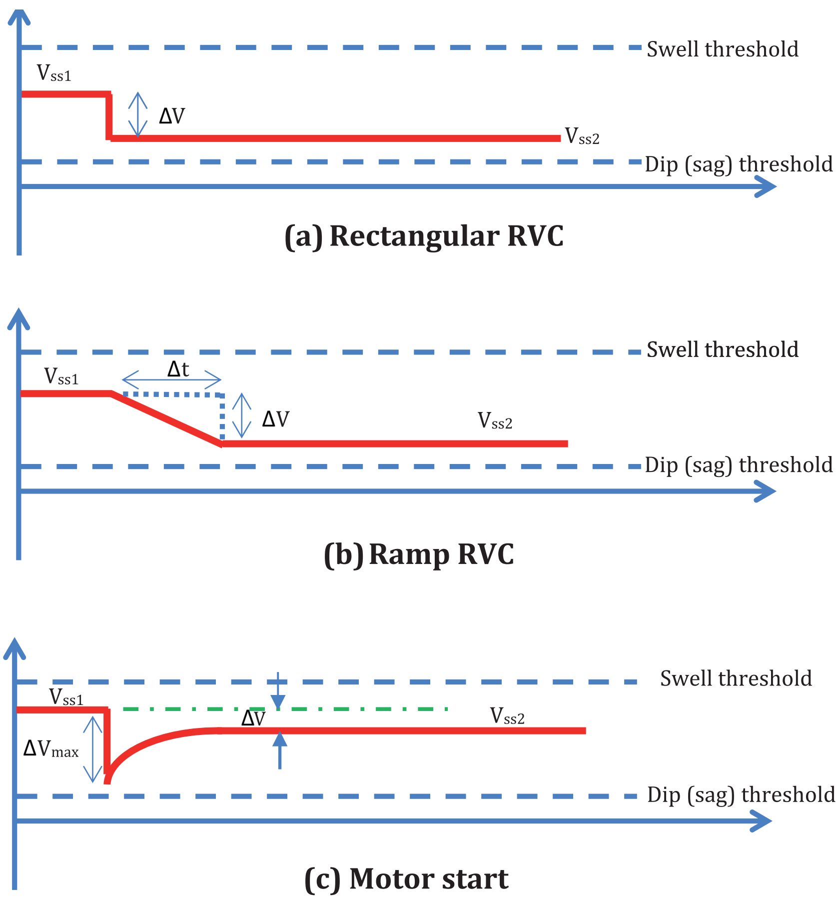



Fig. 1 Different types of rapid voltage changes

# 2. Lamp Flicker, Voltage Fluctuations & Rapid Voltage Changes

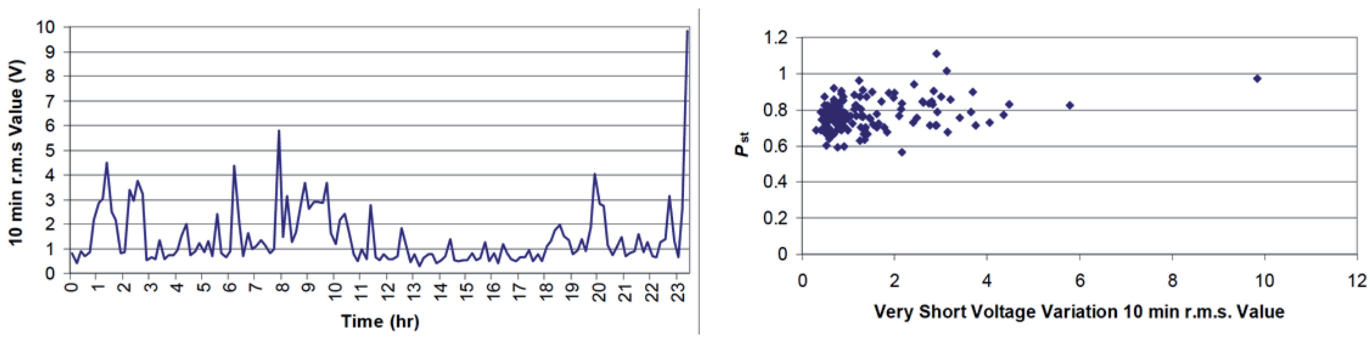
The visual discomfort, and potential other human health impacts, caused by lamp flicker is the primary reason for limiting the voltage changes caused by fluctuating installations [1]. Voltage changes caused by infrequent events such as motor starts, transformer energisation and network switching operations including capacitor connection or disconnection have an influence on flicker (as measured by a flickermeter [6]), but it may be tolerable. However, there is country specific evidence indicating that light intensity changes associated with RVCs are of concern, especially in rural areas where network fault levels are low [3].

Even if RVCs are said to be “non-flicker related” and are tolerable from a flicker perspective, such voltage changes must be limited to [4]:

- Ensure correct performance of power system loads,
- Eliminate the impact on control systems dependent on the phase angle of the a.c. supply,
- Avoid braking or accelerating torques associated with motors, and
- Avoid general malfunctioning of electronic equipment.

Despite evidence documented in [3, 4], there are no wide spread reports of any harmful effects on customer equipment due to RVCs.

A question that can arise is “is there a correlation between flicker indices and RVC parameters?” In this regard, the CIGRE brochure, “Review of Flicker Objectives for LV, MV and HV Systems” [5] presents observed evidence showing that 10-minute variation of RMS voltage changes, as shown in Fig 2(a), are not correlated with the short term flicker severity index (Pst) (refer to the flickermeter definition in [6]), as seen in Fig 2(b). This implies that the information present in one index is not present in the other. Related to the same work, a new voltage variation index defined as ‘3-second half-cycle index’ has been found to be poorly correlated with the instantaneous flickermeter output ($P_{inst}$) (also from [6]) thus indicating that there is a lack of relationship between RVC and flicker indices.




(a) (b)

Fig 2: (a) Very short 10-min voltage variations with time (b) Correlation between Pst and very short 10-min voltage variations [5]

Recent studies [7] have been conducted using both simulated RVC events and RVC events recorded in an actual power system. The simulation results show that there is a clear correlation between the flicker parameters $P_{inst}$, $P_{st,1min}$ and $P_{st,10min}$ (the 1-minute and 10-minute aggregated values of $P_{st}$) and one of the parameters $\Delta V_{max}$ that characterises an RVC event, as indicated in Fig. 1(c). However, field measurements (observed at LV and MV sites) found that the correlation between $P_{st,10min}$ and $\Delta V_{max}$ is not strong. This lack of correlation has been attributed to the fact that, in a 10-minute window, there are numerous RVC events and other disturbances taking place which will be reflected in $P_{inst}$ but not in $P_{st,10min}$ (note that many $P_{inst}$ values are integrated to produce $P_{st,10min}$). The conclusion of the study is that if there is a single RVC event in a 10-minute window, then there will be clear correlation between $\Delta V_{max}$ and $P_{st,10min}$, otherwise there can be a lack of correlation between the same parameters. The results of this work also support the observations [5] illustrated in Fig. 3 and hence the conclusion is that RVC events must be considered in isolation.

For this reason, [7] suggests that an alternative parameter is required to determine the influence of RVC events with disturbing flicker, i.e. $P_{inst,\ max}$ (note that this maximum of the flickermeter instantaneous output is a non-integrated parameter) as the parameter of relevance and not the usual $P_{st,10min}$. Field measurements presented in [7] indicate that there is a quadratic correlation between the $P_{inst,\ max}$ and $\Delta V_{max}$ as shown in Fig. 3 (a)-(c).

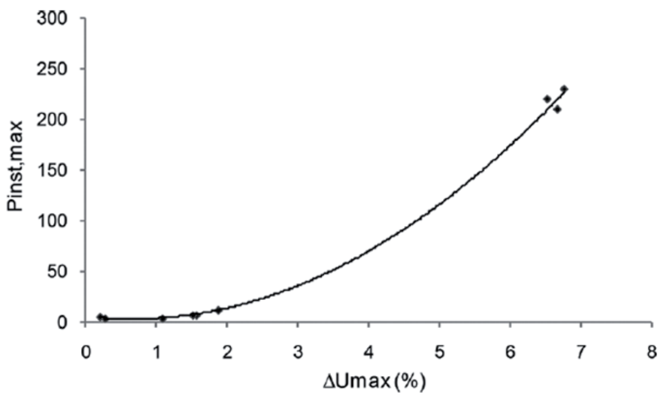



Fig. 3 (a) Correlation between ΔV max and $P_{inst,max}$ at an MV location [7]

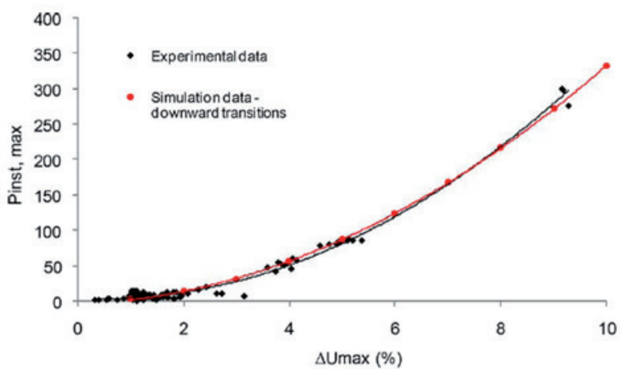



Fig. 3 (b) Correlation between ΔV max and $P_{inst,max}$ at an LV location for downward voltage change [7]

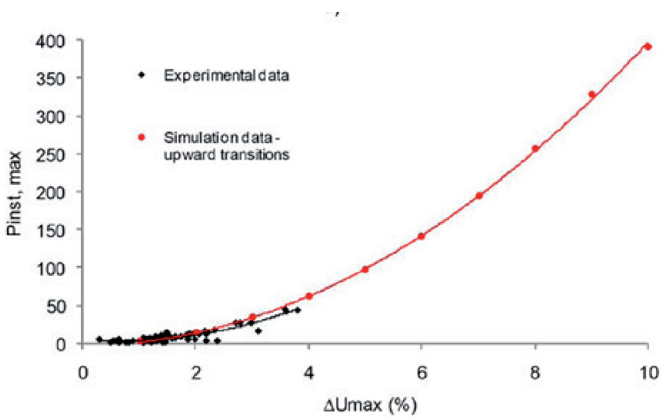



Fig. 3 (c) Correlation between $\Delta V_{max}$ and $P_{inst,max}$ at an LV location for upward voltage change [7]

The observations in Fig. 3 indicate that the $P_{inst}$ generated by a conventional flickermeter can be used as an RVC detector, thus avoiding the need for a dedicated tool to detect RVCs. Although this is the suggestion [7], the algorithm used to detect RVC events that is described in [2] is already implemented in power quality instruments.

# 3. Detection of Rapid Voltage Change Events

The procedure for the detection of a RVC is described in [2]. The key steps and relevant description of the process are given below and illustrated using Fig. 4. A key quantity that requires evaluation is the half cycle RMS values of the input voltage ($V_{RMS(1/2)}$):

• The arithmetic mean of 100 half cycle $V_{RMS(1/2)}$ values including that of the last half cycle is computed and if that value is within the upper and lower RVC threshold levels, it is said that the voltage is in the steady state (i.e. $V_{ss1}$ or $V_{ss2}$ in Fig. 1). The upper and lower RVC threshold percentage values (e.g. 1-6%) are user defined and applied to the arithmetic mean of the 100 $V_{RMS(1/2)}$ values (this can be represented as a box with a variable height and a fixed width corresponding to 100 half cycles moving along the time axis in Fig. 4).

Note: Although RVC upper and lower threshold levels and the arithmetic mean are shown as smooth lines to illustrate the principle, they are in fact dynamic as absolute levels in the direction of the vertical axis in Fig. 4. Also note that actual $V_{rms(1/2)}$ values are also represented by a smooth piece-wise straight lines to maintain clarity.

• If a mean 100 half cycle $V_{RMS(1/2)}$ value exceeds the RVC threshold, then the “voltage-is-steady-state” logic signal is set to FALSE and the RVC event begins. Further, the logic signal is disabled for 100 half cycles of the input voltage, a period over which the voltage is quite dynamic and reaching steady state is not possible. In addition, hysteresis is applied to the RVC threshold limits once an RVC is detected. This implies that tighter RVC threshold limits are applied during the RVC event and that the variation in voltage needs to be smaller than usual before a return to the Voltage-is-steady-state = TRUE status occurs.

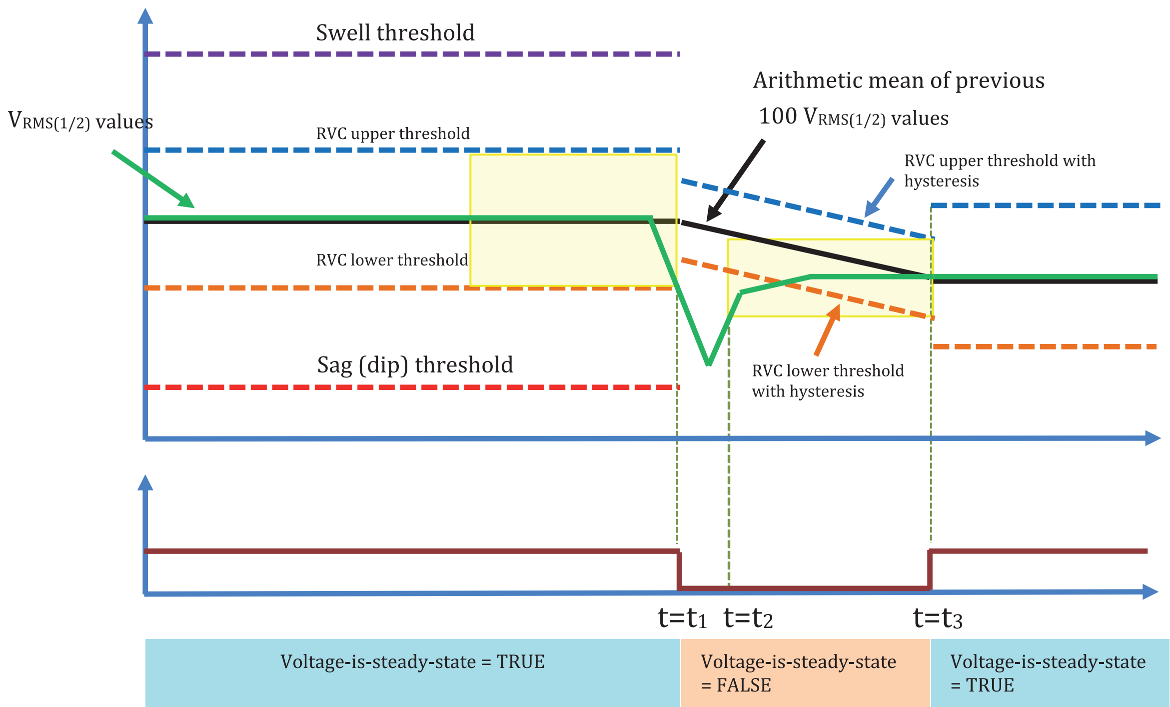



Fig 4. RVC detection process using half cycle RMS values

For illustration purposes assume that the logic level turned from TRUE to FALSE at $t = t_1$ as shown in Fig. 4. The computation of the arithmetic mean of the previous 100 $V_{rms(1/2)}$ values continues. As soon as the logic signal turns TRUE, the RVC event is said to have ended and at that point in time the RVC hysteresis is removed. Note that this end time ($t = t_2$ of Fig. 4) of the RVC can only be established in the post processing stage and the duration of the RVC event is given by $t_{RVC} = t_2 - t_1$. It is important to note that the RVC threshold levels that are applicable to this calculation are based on the arithmetic mean of the last 100 $V_{rms(1/2)}$ values calculated at $t = t_3$.

# 4. Characteristic Parameters of Rapid Voltage Changes

The characteristic parameters relevant to an RVC are as follows:

- Start time $t_1$
- Duration $t_{RVC}$
- ΔVmax calculated at $t_1$, and
- ΔVss calculated using the arithmetic mean values of the previous 100 $V_{RMS(1/2)}$ values established at $t_1$ and $t_3$

These are indicated in Fig. 5 which is a simplified version of Fig. 4.

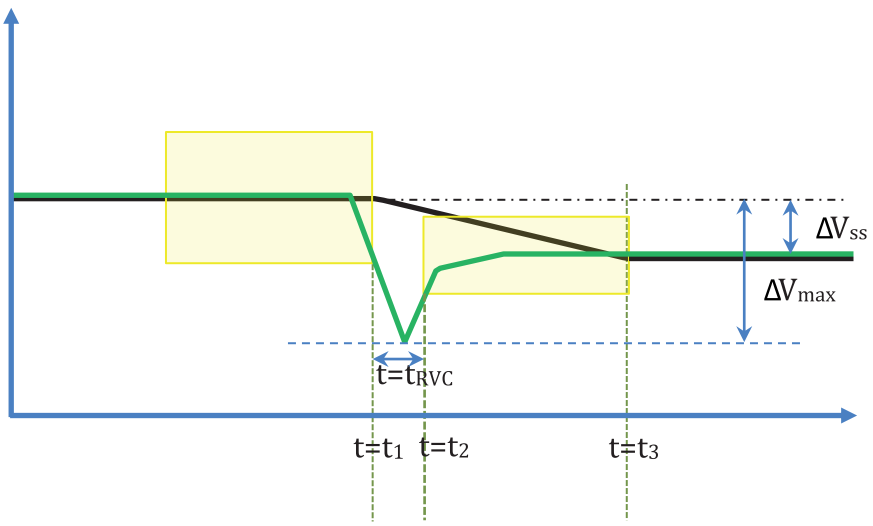



Fig 5. Characteristic parameters of an RVC event

# 5. Limits for Rapid Voltage Changes

The indicative planning limits for rapid voltage changes [1] are given in Table 1.

| NUMBER OF CHANGES (N) | ΔV/VN % | |
|---|---|---|
| | MV | HV/EHV |
| n ≤ 4 per day | 5-6 | 3-5 |
| n ≤ 2 per hour and > 4 per day | 4 | 3 |
| 2 < n ≤ 10 per hour | 3 | 2.5 |

Table 1: Indicative planning levels for rapid voltage changes [1] (VN refers to system nominal voltage)

A summary of practical engineering limits for rapid voltage changes used in different countries is given in Table 2 [7].

| COUNTRY | REPETITION RATE (r) OR NUMBER OF CHANGES | VOLTAGE CHANGE (%) | VOLTAGE LEVEL |
|---|---|---|---|
| USA | all[1] | 3[1] | not specified |
| France | all<br>r > 3/min | 5<br>2 | < 400 kV<br>MV |
| England | r ≥ 0.1/min | $P_{st} = 0.5$[2] | all |
| Canada | 4/day<br>4/day<br>30/hr<br>5/min | 5<br>4<br>3<br>2 | all |
| Australia[3] | r ≤ 4/day<br>4/day < r ≤ 2/hour<br>2/hour < r ≤ 10/hour | 5-6<br>4<br>3 | MV<br>MV<br>MV |

Table 2: Summary of Practical Engineering Limits for Rapid Voltage Changes in Different Countries [7]

1 Unless $P_{st} = 1$ curve becomes more restrictive

2 Maximum voltage change for a given repetition rate is derived from $P_{st} = 1$ curve assuming rectangular fluctuations.

3 Similar (but different) values exist for HV

It is worth noting specific limits developed utilising 60 W incandescent lamp-based field trials (RVC Research Project) were carried out in Norway [3]. Both young and elderly people have been used in the trials where two types of tests were carried out – what is visible and what is acceptable. The RVC levels used in the trials varied from 0.5% – 5% and the types of RVCs covered included rectangular, ramp and motor start as shown in Fig. 1. Based on extensive tests, the Norwegian regulator has decided on the limits given in Table 3. It can be seen that the Norwegian limits allow for significantly more RVC events over a 24 hour period than the limits specified in Table 2.

| NUMBER OF CHANGES (N) | MAXIMUM FREQUENCY PER 24 HOUR PERIOD | |
|---|---|---|
| | $0.23\text{ kV} \le V_N \le 35\text{ kV}$ | $35\text{ kV} < V_N$ |
| $\Delta V_{(steady\ state)} \ge 3\%$ | **24** | **12** |
| $\Delta V_{max} \ge 5\%$ | **24** | **12** |

Table 3: Norwegian Limits (VN represents the nominal network voltage and both ΔVss and ΔVmax are based on the agreed voltage level at the point of connection) [3]

Australian electricity network service providers also specify RVC limits in relevant performance standards where some have adopted the indicative limits in [1] and given in Table 1.

# 6. References


[1] AS/NZS TR IEC 61000.3.7:2012, Electromagnetic Compatibility (EMC), Part 3.7: Limits-Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.

[2] AS/NZS IEC 61000.4.30:2012, Electromagnetic Compatibility (EMC), Part 4.30: Testing and measurement techniques – Power quality measurement methods.

[3] K. Brekke, Rapid voltage changes – definition and minimum requirements, Session 2, paper 0789, CIRED, Prague, 8-11 June, 2009.

[4] A. J. Schlabbach, D. Blume, T. Stephanblome, Voltage quality in electrical power systems, Inst. of Elect. Eng, London, UK, 2001.

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[6] AS/NZS 61000.4.15:2012: Electromagnetic compatibility (EMC) - Testing and measurement techniques - Flickermeter - Functional and design specifications.

[7] J. Barros, J. J. Gutiérrez, M. de Apráiz, P. Saiz, R. I. Diego and A. Lazkano, “Rapid Voltage Changes in Power System Networks and Their Effect on Flicker,” in IEEE Transactions on Power Delivery, vol. 31, no. 1, pp. 262-270, Feb. 2016.

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