GE
Digital Energy

UR Series

G30/G60 Overcurrent and Overvoltage Function Response During Generator Startup at Low Frequencies

Technical Note

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This document describes the performance of UR G30 and G60 phase instantaneous overcurrent and neutral overvoltage functions during generator startup at low frequencies. These functions can be applied during static starting of a combustion gas turbine (CGT) generator. The impact of frequency deviation on the protection function is explained in technical paper [1]. The G30 and G60 generator protection systems, as part of the UR series, provide frequency tracking over a wide range (3 to 70 Hz), and this frequency tracking ensures that the phasor estimation is accurate in case of variations in the applied frequency, such as the static starting of a gas turbine generator.

Introduction

Static starting of a CGT is carried out with a load commutating inverter (LCI) and an adjustable speed drive (ASD) system, to motor the synchronous machine and coupled turbine. Excitation to the field is controlled to limit stator voltage to prescribed levels to maintain constant volts per hertz during the process. The process of static startup of a CGT takes 30 to 60 minutes, and it includes various stages, such as acceleration, purging, coast down, ignition, and acceleration to full speed. During static startup, the voltage increments in conjunction with machine speed to limit the V/Hz. Also, during initial full-speed acceleration stage, the field is excited to bring the generator voltage to the ceiling starting voltage, typically 25%. Therefore, the initial root mean square (RMS) symmetrical short circuit current can be as low as 0.25 times the normal condition initial RMS symmetrical short circuit current (when generator terminal voltage is maintained at 1 pu [2].

It can be inferred from this discussion that during static startup of a CGT, there are two major challenges faced by multifunctional digital relays:

- Low frequency system frequency protection (below 20 Hz)
- Low fault levels (short circuit current and neutral voltage) when the synchronous machine voltage is maintained lower than 1 pu

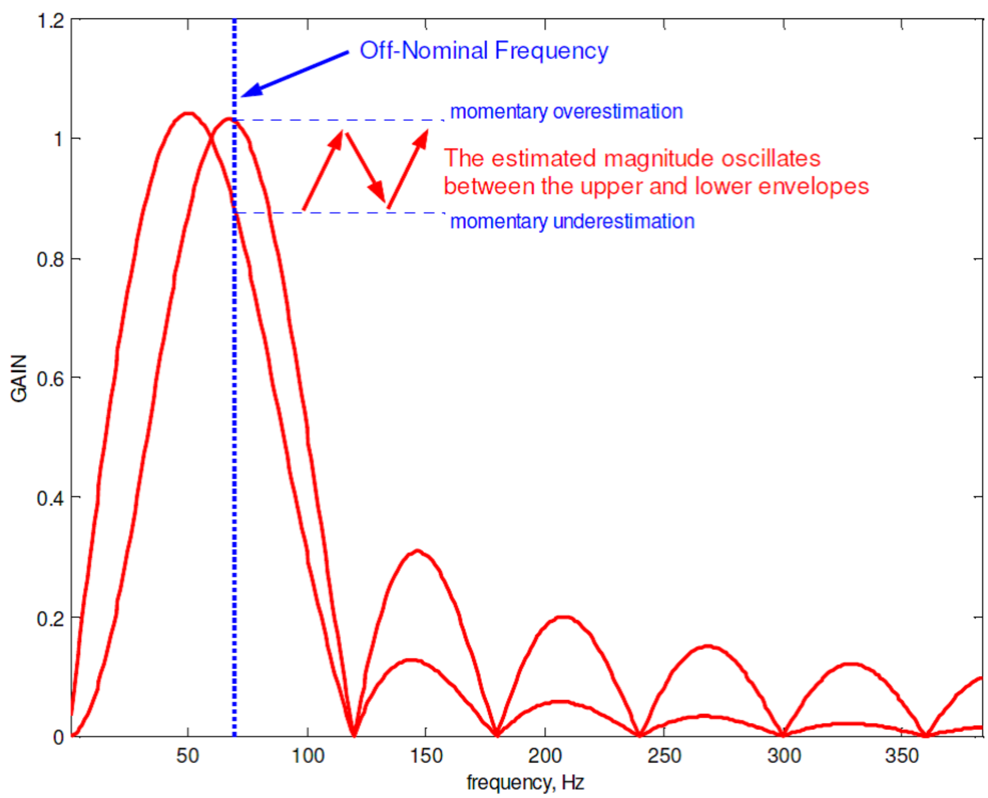
In response, phase overcurrent protection (instantaneous overcurrent with defined delay) and neutral overvoltage are used to protect the generator during static starting.

Impact of low frequency on protection functions

Typically, digital relays employ Fourier-based methods to calculate phasor values from samples of voltage and current. The Fourier transformation produces an accurate estimation of the fundamental component and rejects harmonics when taken over a full power cycle. In case of change in the system frequency, the G30 and G60 digital relays can track the frequency from 3 to 70 Hz [1]. In order to prevent frequency errors due to noise or system disturbances, the relays have a secure protection function with a few cycles of delay (depending upon the difference between new/actual frequency and old frequency) while tracking to the correct frequency. This short time lag of a few cycles can cause a difference in signal and tracking frequencies for a short time. As shown in Figure 1, in case of such difference in frequencies, the two filters display different gains yielding a phasor estimate with some ripple, and the phasor instantaneous value becomes inaccurate.

The delay due to frequency tracking can cause frequency mismatch for a very short time (a few cycles), which can add delay in protection operation, but does not inhibit protection operation, as the frequency tracking is operational from 3 to 70 Hz. This delay is mainly due to additional security checks and filtering. **When protection elements used during static startup are set properly (by considering the delay and inaccuracies), the impact of low frequency on protection functions is minimized.**

Figure 1: Typical digital Fourier transform (DFT) phasor estimator under off-nominal frequency [1]



Although the relay can sample the input signals as often as 64 times per power cycle, the execution of the protection algorithms, known as a protection pass, occurs less often, typically at 4 to 16 times per cycle. This is done in order to reduce loading on the central processing unit (CPU) and digital signal processor (DSP) and to reduce data transfer rates between the CPU and DSP, thereby realizing the required speed of operation. At each protection pass, in addition to running protection algorithms, the relay executes programmable logic, evaluates input/output states, refreshes metering data, and so on. To avoid nuisance operation due to transients and noise, the protection function is allowed to issue a trip command only if element comparators are satisfied for a fixed number of consecutive protections passes, typically 1 to 5.

To summarize, the following factors contribute to slowing down the protection operation during low frequencies:

- Duration of the power cycle
- Frequency tracking mechanism employed
- Security conditions and counters employed
- Signal processing / filtering employed
- The number of times that the function is executed per power cycle

Response of instantaneous overcurrent protection

Figure 2 shows the response of instantaneous overcurrent (IOC) protection at various low frequencies. The vertical bars represent the time of operation (TOP) of the IOC element (in cycles of signal frequency). The time of operation of IOC at 60 Hz nominal frequency is around 1.5 cycles (26 ms) for the worst-case boundary condition when the fault current is only 2% higher than the pick-up value. Observe that IOC elements operate within 1.5 to 2 cycles of signal frequency (that is, at 6 Hz, IOC operates in 1.314 cycles or 1.314 / 6 = 0.219 seconds). Note that as the fault current value increases, the TOP is reduced to almost 1 cycle, due to fewer security checks. Moreover, the results are taken for the worst scenario when a fault appears immediately at the low frequency step. Hence, these results also include the delay of frequency tracking. If a fault appears after a few cycles of generator-startup, this allows frequency tracking to reach the right value, and the incurred delay is much lower.

Figure 2: Time of operation of IOC at lower frequencies

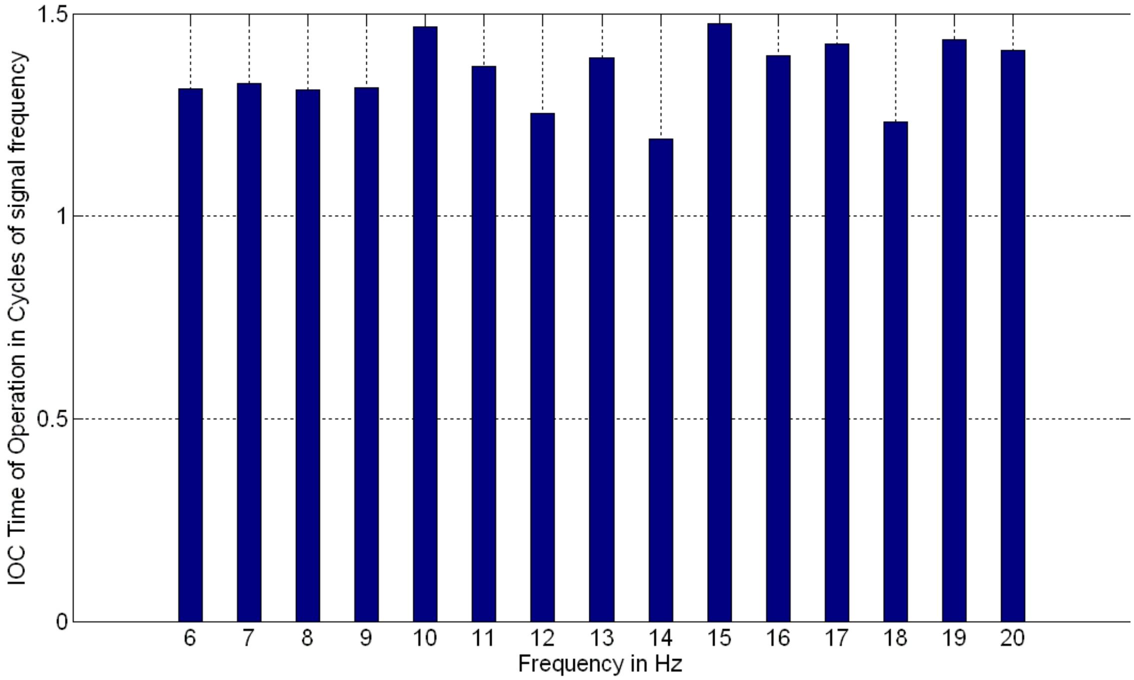
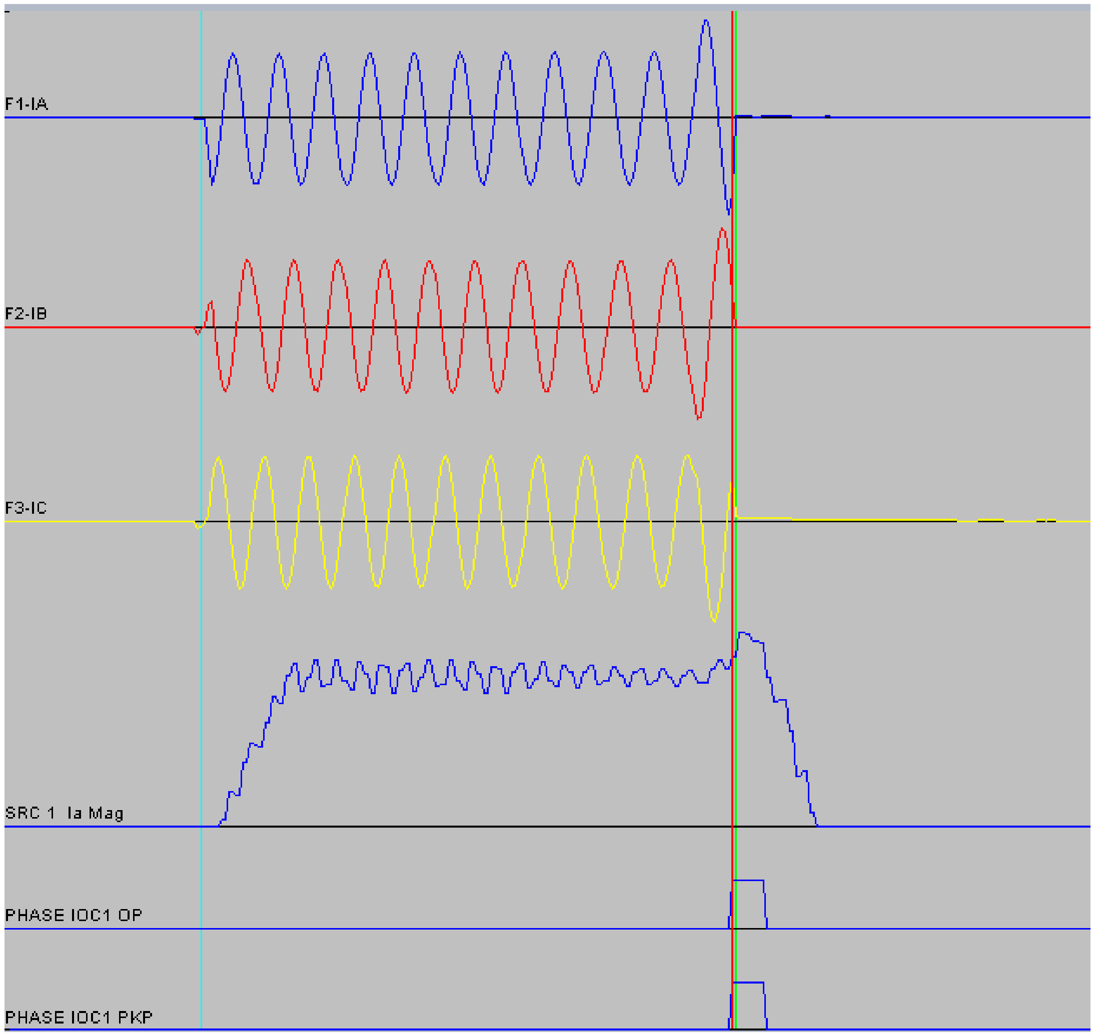


Figure 3 shows the oscillography for IOC operation with no intentional delay, at 5 Hz. The oscillations in measured current magnitude gradually damp out due to the frequency tracking feature of the G30/G60.

Figure 3: G60 oscillography for overcurrent protection at 5 Hz



Response of neutral overvoltage protection

Figure 4 shows the response of neutral overvoltage protection at various low frequencies. The vertical bars represent the TOP of the neutral overvoltage protection element. This TOP at 60 Hz nominal frequency is 2 cycles (or 33 ms) for the worst-case boundary condition when voltage is only 10% higher than the pick-up value. Observe that the neutral overvoltage elements operate in around 3 cycles of signal frequency (that is, at 6 Hz, the element operates in 1.9344 cycles or 1.9344 / 6 = 0.322 seconds). Observe that as the voltage value increases, the TOP reduces to almost 1 or 1.5 cycles due to fewer security checks. Moreover, the results are taken for the worst scenario when overvoltage appears immediately at the low frequency step up. As such, these results also include delay of frequency tracking. If a fault appears after few cycles of generator-startup, this allows frequency tracking to reach to the right value, and the incurred delay is much lower.

Figure 4: Time of operation of neutral overvoltage at lower frequencies

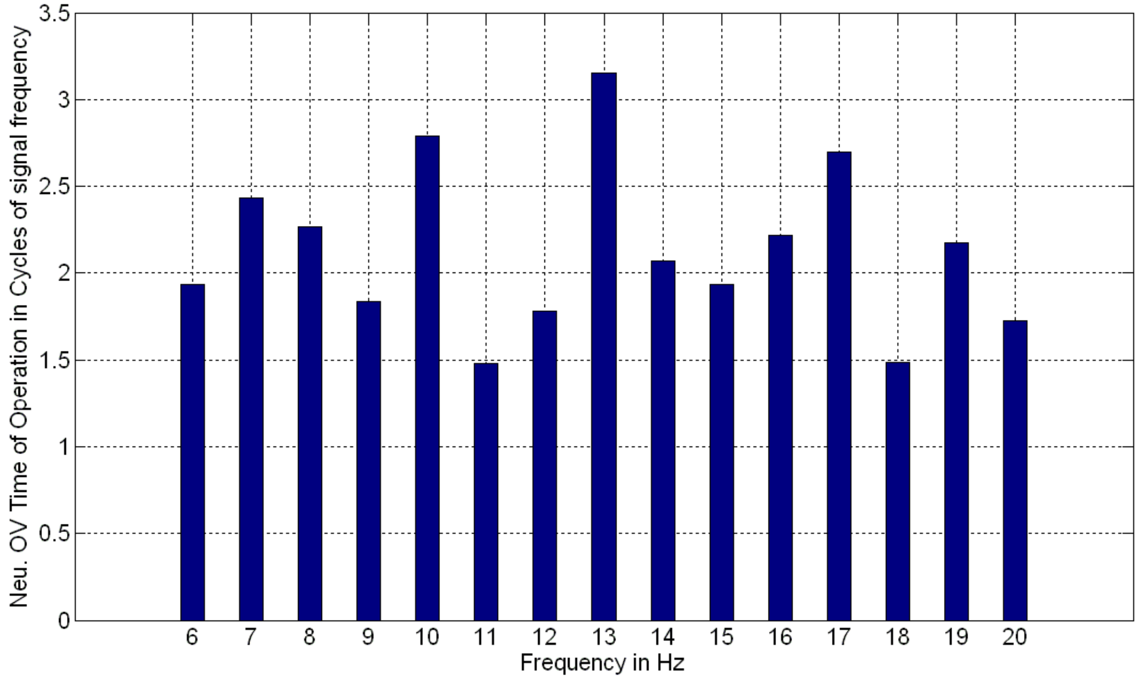
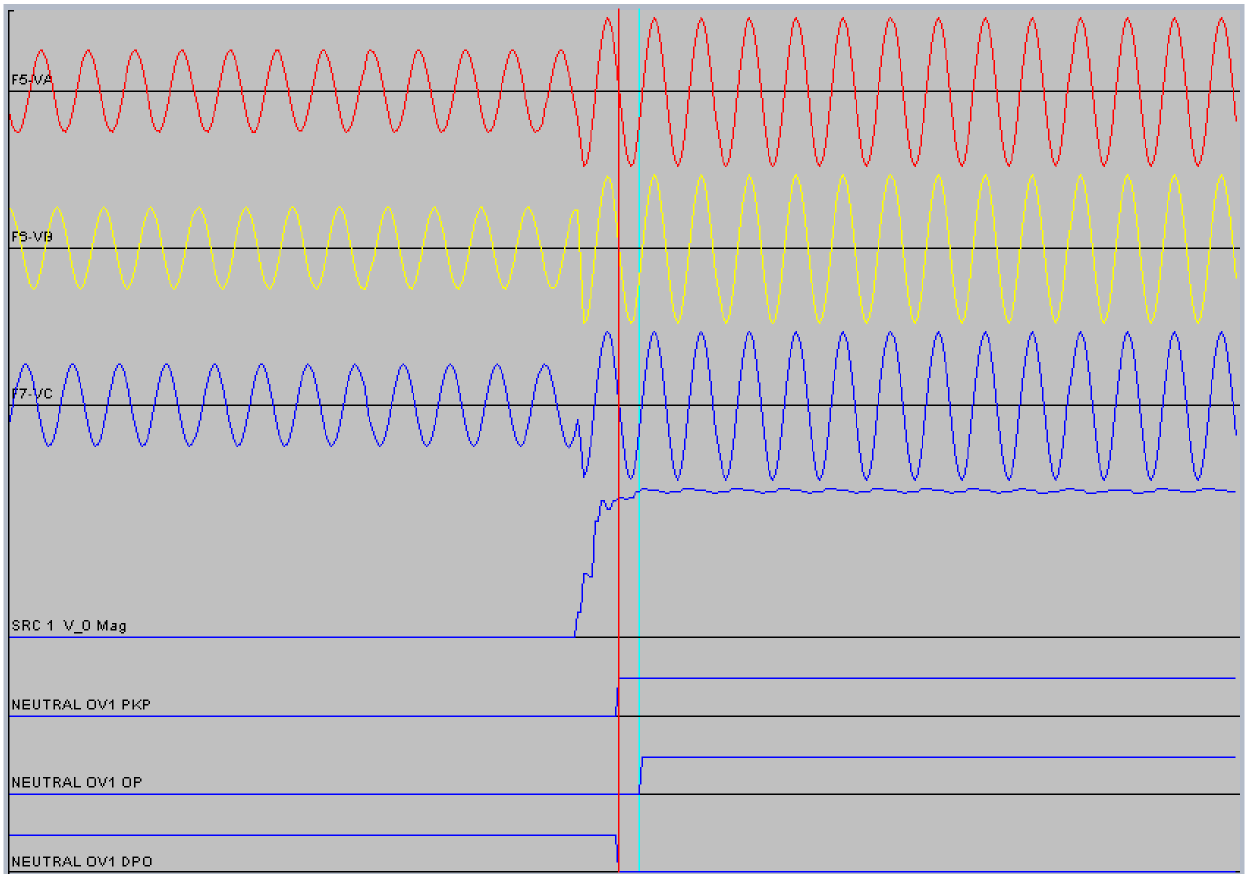


Figure 5 shows the oscillography for neutral overvoltage protection operation with some intentional delay, at 5 Hz. The oscillations in measured current magnitude gradually damp out due to the frequency tracking feature of the G60.

Figure 5: G60 oscillography for overvoltage protection at 5 Hz



Recommendations

RMS symmetrical short circuit current during static startup (due to lower terminal voltage) is lower than the normal-condition RMS symmetrical short circuit current (when generator terminal voltage is maintained at 1 pu) [2]. Therefore, it is recommended to set dedicated static start-up protection functions with the following considerations:

- Enable protection elements only below 20 Hz frequency. This can be achieved using FlexLogic functions of the G30/G60 or by setting group change.
- Lower the pick-up value, for example 0.25 to 0.5 times the normal pick-up value and higher than 1.2 pu
- Reduce the intentional time delay (the time delay setting) by considering delay in measurement due to lower frequency, as illustrated in this document
- When the G30 or G60 is equipped with GPM-S (stator sub-harmonic injection modules for 100% stator ground protection), inhibit the low frequency protection function to 15 to 25 Hz, in case the estimated impact of injection is not considered while setting the pickup value

References

[1] Ilia Voloh, Dale Finney, and Mark Adamiak, "Impact of Frequency Deviations on Protection Functions," Georgia Tech Protective Relaying Conference, 2009.

[2] IEEE PSRC Working Group J-2 report on Protection Considerations for Combustion Gas Turbine Static Starting, 2011, available at www.pes-psrc.org.