FLICKER PROPAGATION STUDY IN A TYPICAL DUTCH GRID

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ABSTRACT

In the last couple of years, the Dutch grid operators register many complaints from the customers about flicker related problems. The power quality monitoring (PQM) in the Dutch grid indicates that the average long-term flicker indicator ($P_{lt}$) in the low voltage (LV) network has an increasing trend. In this paper a typical Dutch medium and low voltage network is simulated to analyse the flicker propagation behaviour at different parts of the network. The influences of switching of disturbing LV loads on flicker generation (with and without background flicker pollution) are also studied. Further, the flicker transfer coefficients between MV and LV networks are calculated.

INTRODUCTION

In the Dutch networks, flicker-related problem has increased in the last decade. The reason for this is mainly the increase of high-power equipments and installations that are connected to the network without analyzing grid impedance or the proper use of mitigation techniques. It is an annoying problem for the network users and can affect ergonomics of the production environment. In extreme cases, it might cause health problems like headaches, reduced concentration level, vision-related illnesses, epilepsy, etc.

It is observed that many flicker-generating sources are located in the LV network. When power demand in the network suddenly changes (for example a heavy motor starts-up), the current changes and a rapid voltage variation occurs at the network connection point. This can lead to objectionable flicker, depending on the source current, grid impedance and frequency of the voltage fluctuation.

A model of a modern Dutch medium (MV) and low voltage (LV) network has been set up. In that test network, different cases with flicker sources at the LV customer’s connection points are simulated. The instantaneous voltage variations, found from different cases, are then further evaluated by using a UIE/IEC flickermeter simulation model to obtain the short-term flicker indicator ($P_{st}$) values. Moreover, any co-relation that might exist between the switching intervals of two consecutive loads is studied. Furthermore, the flicker propagation and the flicker transfer coefficients between the LV and MV networks are calculated.

FLICKER SEVERITY INDICES

The flicker severity level is measured in units of perceptibility. Two important parameters are used to indicate the severity of flicker: a) short-term flicker indicator ($P_{st}$) that is measured for a ten-minute period and b) long-term flicker indicator ($P_{lt}$) that is estimated over a two-hour period.

The $P_{st}$ value at a network point can be calculated by using empirical equations (1) and (2) [1].

$$t_f = 2.3 \cdot (F \cdot d_{max})^{0.6}$$

In the standard IEC 61000-3-2, the shape factor for a motor start voltage characteristic is given [1]. The maximum value of $F$ is approximately 1 and is taken for the analysis of this paper. Further, the $P_{st}$ value can be calculated by summing up all flicker impression times during the evaluation time period $T_p$.

$$P_{st} = \sum \frac{t_f}{T_p}$$

The European Standard EN50160 [2] gives a requirement for the long-term flicker indicator ($P_{lt}$) in the MV and LV public networks. This standard states that in any period of one week $P_{lt}$ caused by voltage fluctuations should not exceed ‘1’ for 95% of the measuring time under normal operating conditions. The relationship between $P_{st}$ and $P_{lt}$ is shown in equation (3).

$$P_{lt} = \sqrt{\frac{\sum P_{st}^\alpha}{12}}$$

‘$\alpha=3$’ is commonly used for most types of flicker sources where the risk of coincident voltage change is small.

The ‘Dutch Netcode’ follows the same principles for flicker as the standard EN50160. The standard gives restriction for voltage variation (10 minutes mean rms
values) based on the 95% assessment criteria. However, current discussion is to change the limit to 99% instead of 95%. Also a 100% criterion is set on a $P_{lt}$ of 5.

**FLICKER TREND IN DUTCH GRIDS**

Every year the Dutch grid operators register many complaints about light flicker and other related problems of the customers. The PQM report of 2007 [3] indicates that the $P_{lt}$ values over the years (1998-2007) in the Dutch LV network for 95% of the measurement times lies between 0.20-0.60; with values up to 1.50 for 95% of the measured data. The same for the MV networks is in the range of 0.15-0.30 and that for the HV networks lies between 0.10-0.25. Figure 1 shows the $P_{lt}$ values of 2007 at the randomly selected monitoring locations in the LV network for 95% and 100% of the measured data. It can be noted that some of the locations the $P_{lt}$ value exceeds 1 which is the EN50160 standard limit for the case of 95% of the measured time.

The increasing trend for the $P_{lt}$ in the Dutch grid draws attention of the network operators and they started to analyze the problem in detail. Moreover, the Dutch networks were developed based on no such specific planning level value for flicker or other PQ aspects. So, it is necessary for the grid operators to acquire knowledge about the realistic planning level for designing future new grids. A planning level value is utilized as a reference value in setting the emission limits for different loads and installations connected to certain voltage levels. It is necessary to set different planning levels at different voltage levels to account various emissions contributed by both upstream and downstream networks.

**MOTOR START SIMULATIONS**

To study the flicker severity and its propagation behavior in the Dutch grid, a typical MV and LV network model is developed using the simulation tool ‘Power Factory’. A detailed description of the test grid can be found in the reference [4]. Typical three phase induction motor model is used as a flicker generating source at the customer’s terminal. When the motor starts, an instantaneous voltage fluctuation occurs at different nodes in the network. The instantaneous voltages at different nodes during the switching operations are recorded and used as input for the flickermeter model to calculate the $P_{st}$ values.

**Simulation tools used**

The induction motor start simulations are done in ‘Power Factory’. During the motor start, it draws a high inrush current and produces voltage variations in the network. These voltage variations can cause large voltage drops, depending on the network structure and the grid impedance. Each voltage step change (rms value) is noted, and $P_{st}$ is calculated using equations (1) and (2).

The flicker severity of the motor start voltage change can also be measured by using the flickermeter model. The input of this model is the instantaneous voltage value. So, the motor start-up instantaneous voltage variations are provided to the flickermeter for analysis. This model is developed in Matlab/Simulink. It is a simulation model of the UIE/IEC flickermeter that is built based on the flicker response of a coiled filament gas-filled 230V, 60W or 120V, 60W incandescent lamp. Detailed description of this flickermeter model is given in the reference [5]. This model utilizes the instantaneous values; while the only rms values are considered in the empirical method. So, $P_{st}$ values calculated by the flickermeter model are considered to be more precise.

**Case study without background flicker**

It is assumed that in a feeder maximum two motors per phase start at an instant. So, in this analysis, two three phase motors are considered that start simultaneously in a LV feeder of the test network. First, the simulation is done without any background flicker in the test network which means that no flicker is brought by the MV network into the LV network. Later, simulations are also done with background flicker. The network schematic is shown in Figure 2. At point A, a 400kVA, 10kV/0.4kV transformer is connected. At the 400V bus bar B, five outgoing LV feeders are supplying households and small commercial customers.

![Figure 2: LV network model with customer’s motor loads](image-url)
Two motors that are connected at nodes D and G in the LV network start simultaneously. They are three-phase, 4kW, two poles, star-connected induction motors which have power factor 0.85, efficiency 83%, and an inrush current of 6.3 times the nominal current. It is considered that both motors start once per minute and are switched off 10s later. The synchronized flicker level is measured at node points A, B, C, D, E, F, G, H, and I to verify the flicker propagation behaviour at different locations in the network. Figure 3 shows various node rms voltages at the selected points during the start-up and the switch-off.

At time 20s the motors start. About 0.5 sec after the motor-start, the voltages at different nodes are stabilized. At time 30 sec, both the motors are switched off. The whole simulation is carried out for 2 minutes. Figure 3 shows that significant voltage drops (more than 2%) occur at D, E, F, G, H, and I nodes. However, voltage drops at point B and C are relatively low (within 1%) and the voltage change at point A of the 10kV bus is almost negligible. So, the nodes that are located outside the test feeder are less affected by the motor-start event. The maximum voltage variation at 'G' is: 3.0% (during motor start-up), 1.4% (when the stable condition is reached after the motor start-up) and 1.6% (after motor is switched off) respectively. The instantaneous voltages during motor start event are also recorded for different nodes and are fed to the flickermeter to calculate $P_{st}$ values. A comparison is done to check the accuracy of the flickermeter model. At point G, the $P_{st}$ value calculated by the flickermeter is 1.27 (see Figure 4) while it is 1.19 when calculated analytically using equations (1) and (2).

**Case study with background flicker**

Many disturbing loads (e.g. big motors, capacitor banks etc.) are connected to the MV and HV networks that make the grid voltage waveform distorted. A significant proportion of flicker generated in the upstream networks is transferred to the downstream networks. In the present analysis, it is assumed that big motors are starting in the MV network that produce background flicker. The three background flicker pollution cases are considered: a) no MV flicker emission ($P_{st}=0$), b) high $P_{st}=0.7$, c) low $P_{st}=0.2$. The LV flicker sources remain unchanged for the different simulation cases. The $P_{st}$ values at various nodes of the test network are shown in Figure 4.

![Figure 3: Voltage variations (rms) during motor start-up](image1)

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![Figure 4: $P_{st}$ values at different nodes of the test network](image2)

Figure 4 indicates that $P_{st}$ values at different LV nodes increase slightly when the MV background flicker level is significantly high. However, the background pollution has very less impact on $P_{st}$ values of LV nodes when a number of flicker sources are present in the LV network. $P_{st}$ value found at G is higher than that of D with the same type of disturbing loads at both the locations. There are two reasons: a) grid impedance at G is higher than D, b) generated flicker is transferred from D to G at a higher rate than that of G to D. The evaluation results also show that the flicker level at the end of feeder (at I) is quite high and is not attenuated much. However, $P_{st}$ value found at 400V common bus (at B) is relatively low which signifies that the flicker emission is reasonably attenuated when it reaches at the beginning of the LV feeder. The impact of flicker, produced by the LV nodes, reduces even more when it reaches to the MV network (at A).

**Influence of different loads switching interval**

Figure 5 shows the $P_{st}$ values at various points when two motors have a definite time gap between their start-ups.

![Figure 5: $P_{st}$ versus switching intervals](image3)
Figure 5 shows that the $P_n$ value is maximum when the motors start simultaneously. With a time gap between their start-ups, the $P_n$ values are quite lower than that of simultaneous starts. These values remain almost constant when the motor switching time intervals are increased. However, they increase rapidly when the motor switching frequency is increased. To limit the flicker severity, the number of motor-starts per hour in a feeder has to be restricted as indicated in the standard IEC 61000-3-3 [1]. Alternatively, proper mitigation device can be used to restrict motor inrush currents and to improve the $P_n$ value.

**FLICKER PROPAGATION BEHAVIOR**

The synchronous flicker measurement at different nodes gives an impression of the flicker propagation behaviour in the network when one or more disturbing sources are present in the power system. The flicker level itself is directly related to the grid impedance of the network. From the motor-start simulation results, the flicker transfer coefficients and the propagation factors can be calculated. Those values are found by measuring $P_n$ values of two points at the same instant. Consider a flicker source at point G and the evaluation point at B, the transfer coefficient is defined as:

$$ T_{GB} = \frac{P_{st,G}}{P_{st,B}} $$

The transfer coefficient indicates the propagation of the flicker emissions from a flicker producing source to another point in the network. However, in practice at least two simultaneous flicker producing sources are assumed to be present in the network and contribute flicker emissions. So, the total $P_n$ value measured at a point will be the combination of the contributions from both the sources. Therefore, a term ‘flicker propagation factor’ can be introduced that compares the total $P_n$ value of a point with respect to the $P_n$ value of a chosen reference point. Table 1 shows the flicker transfer coefficients and propagation factors at different points of the test network.

The flicker transfer coefficient from the LV to the MV network is found around 0.15 (from B to A) for the test network. The propagation factor at various points in the LV network varies significantly (see Table 1), depending on the location of flicker sources. The transfer coefficient from the MV to the LV network is found close to unity for the case with background flicker pollution in the MV network and no flicker source in the LV network (see (d) of Figure 4). The knowledge of propagation factor and transfer coefficient is used to determine the emission limit at various customers’ installation points in the network.

**CONCLUSION**

The analysis of this paper shows that the flicker level strongly depends on the voltage variation and switching frequency of the loads, but hardly on the switching intervals of different loads. The flicker level increases with the increasing grid impedance. The study results indicate that the propagation of flicker at different points in the LV network varies significantly, depending on the location of flicker sources. The flicker transfer coefficient from the LV to the MV network is around 0.15 and it is close to the value of 1.00 when the flicker is propagated from the MV to the LV networks. It is also noticed that the flicker propagation is larger when the disturbance is transferred from the upstream to downstream part of the network than the other way round. In the next phase of the research, the flicker emission limits for all customers at different voltage levels will be evaluated. The planning and compatibility levels can then be derived, which will be helpful for the grid operators in designing the grids.

**REFERENCES**

1. IEC 61000-3-3, Edition 1.1, 2002-03: “Limitation of voltage changes, voltage fluctuations and flicker in public low voltage power systems, for equipment with rated current $\leq 16\,\text{A per phase and not subject to conditional connection}”. IEC, Geneva, Switzerland.


