A Review of Transient in Electrical Systems

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Abstract- The paper reviews transient which is a disturbance in electrical/electronic systems. It produces harmonics, overcurrents and overvoltages resulting into colossal damage to equipment. The objective is to identify the causes and effects of transient. Secondary sources were used for the study. The paper posits that there is high rate of electrical/electronic equipment failure which posses' great concern to designers and users of electrical/electronic appliances coupled with inadequate knowledge and selection of appropriate protective devices. Consequently, mitigation methods involving suppressors which block or clamp and or conduct transient are presented in order to prevent or reduce its effects, thereby, protecting facilities from being destroyed, essentially to achieve operational effectiveness and service continuity.

Indexed Terms- Arresters, lightning, overvoltage, switching, transients

I. INTRODUCTION

Transient is a periodic disturbance that can last for milliseconds, a momentary variation of current, voltage or frequency for only a short time. It may also be seen as a brief change of state in electrical systems (Electrical Engineering Commentary, 2013). In Piasecki (nd), transient in power networks result in overvoltages and oscillation superimposed on the phase voltages and currents which originate from both internal (switching ranked highest) and external (lightning most disturbing) sources.

Malfunctioning, failure and damaging of electrical /electronic equipment commonly result from transient events. This study therefore is intended to discuss some causes, effects and mitigation methods in order to reduce maintenance and replacement cost associated with such items. Theoretical approach is employed using secondary sources. The study posits that users of electrical/electronic equipment should also select appropriate protective devices. Surges associated with transient system are shown in figure 1.

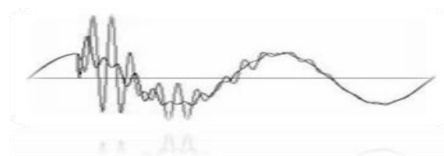

Figure1.Transient system. Source: (Electrical Engineering Community, 2013).

II. EXTERNAL SOURCE OF TRANSIENT (LIGHTNING)

Lightning is produced by nature maintaining a balance between positive and negative charges in the atmosphere (Altas, nd). Though, the exact knowledge of specific occurrence of lightning is not predictable (Martzloff, 2004). Lightning is the discharge of atmospheric electricity that takes place mostly during rainy seasons and in Nigeria, lightning related human injuries and deaths are very high about 500 deaths and 5,000 injuries annually (Buba and Gome el tal 2012). Peak current can be up to 200 kA and voltages above 1 MV causing power system faults such as supply interruptions and voltage sags in distribution network (Smith et al, nd). According to Caldwell (2007) lightning temperatures may rise to about 50,000°F, hence, is highly destructive. A lightning model, with and without continuing current is illustrated in figure 2, demonstrating that with continuing current , more lightning energy is involve.

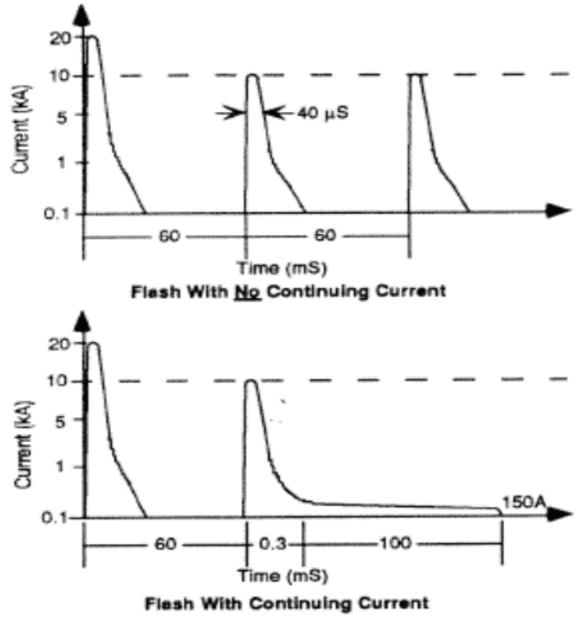

Figure2.Typical Lightning Model, without and with continuing current. Source: www.onsemi.com

A severe lightning strike produces heat which ignites combustible materials. Similarly, the electric field strength associated with lightning strike from distance away may still result into catastrophic damage to electronic systems. Therefore, it is important to protect equipment from such strikes. Induced voltages from lightning are sometimes equally very high and destructive too including distance flashes, demonstrated in figure 3.

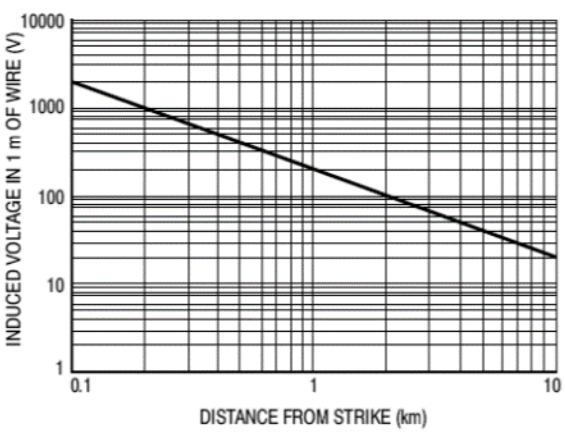

Figure 3. Voltage Induced by Nearby Lightning Strike: Source; www.onsemi.com

Underground cables are not spared by lightning destruction, because the earth is more or less transparent to lightning radiated fields. In Nema (2015), transient overvoltages from lightning may directly contact facilities electrical system or, indirect or nearby lightning which induces electrical surges on power or communication systems.

III. INTERNAL SOURCE OF LIGHTNING (SWITCHING)

Switching operations produces transient overvoltages or flashesovers that can damage insulations as well as power outage in some cases. They occur within low frequency range, below 1 kiloherze Woodwork (2008). It usually last within 50-500microseconds (Altas, nd). Such transients may be very difficult to suppress as it carries enormous energies (Marzloff, 2004). Switching transients may be impulsive or oscillatory and are self-induced during operations involving circuit breakers (chopping and restrikes, reclosers, switching or disconnecting switch, capacitor bank, relay etc. (Electrical Engineering Community, 2012).

From experiment, Bak and Søgaard (2008), using a shunt reactor rated 100Mvar with a 400kv overhead lines results in overvoltage of 132%, though, decay in seconds after switching off. According to www.onsemi.com (2008), inductive switching transients occur when a reactive load, such as motor, solenoid or relay coil, is switched off and the rapidly collapsing magnetic field induces transient voltage across an inductive load's winding expressed as:

$$V = - L \left(\frac{di}{dt}\right) \qquad (1)$$

where L is inductance in henrys and di/dt is the rate of change of current in Amps per second. Such transients can occur from a power failure, the normal opening of a switch or a load failure. The stored energy within the inductance during power interruption is equal to:

$$\omega = \frac{1}{2} L i^2 \qquad (2)$$

where ω = energy in joules, L= inductance and i = is instantaneous current in amps at the time of interruption.

Capacitor switching can also be troublesome if the switch restrikes after current interruption (Marzloff, 2004). Capacitor switching transients are difficult to pinpoint and are second most common power quality event, after voltage sags, capable of disrupting any load that cannot tolerate overvoltage subcycle transients, including adjustable speed drives, data communication systems, and process controls (PQView,2015). Switching an unloaded transformer associated with a capacitor bank produces dynamic overvoltage's (Cooper Power System, 2000). During steady state operation of an AC power system, harmonics in the transformer magnetizing current represents a small percentage of the load current. But, on energizing a transformer produces fairly high level of harmonic current in the transformer inrush current. Similarly, when transformer is switched with capacitors, resonant condition may occur leading to dynamic overvoltage.

IV. CAUSES OF TRANSIENTS

- Facility load switching
- Energized line on/off
- Capacitor bank switching
- Tap changing in transformers
- Flying objects: when flying objects bridge line conductors, line voltage will increase abruptly (transient)
- Tree branches falling on poles /lines; in the event of this happening, within 2-4 seconds, short-circuit ensures, sparking result which can burn tree leaves. This sometimes takes more time than the main transient and termed sub-transient.
- Magnetizing inrush current in transformers: In switching on a transformer, a ferroresonance causes the iron core to vibrate for a few seconds. Harmonic frequencies now develops to such an extent expressed as;

  $$F = F1 + Fh \qquad (3)$$

  where F = power frequency, F1= fundamental frequency, Fh = harmonic frequency. The terminal voltage V rises E + Vh where E= supply voltage Vh= harmonic voltage, and the system current I = It + Ih (4)

  where It= normal current Ih= harmonic current, culminating into switching magnetizing inrush current inducing overvoltage detrimental to transformers and induction motors (Ezechuckwu ,2013).
- Switching on induction motors
- Arcing in circuit breakers and contactors
- Head changes caused by collapse of load voltage
- Short-circuit in transmission line
- Loss of tie between two subsystems
- Sudden application and removal of large loads
- Power system recovery from outage
- During fault clearing or interruption
- High impedance earthing . This is particularly when in a three-phase system; fault develops in any line leading to rise in the other line voltages (Ezechukwu, 2013)
- Electrical faults such as equipment failure causes high current to flow to ground or from phase to phase (Martino, 1996)
- Switching on both lighting and electric motors
- Sources of internally generated transients from alternating current systems include home appliances such as air conditioners, circulating pumps, fans, washing and dryer machines, refrigerators, freezers, submersible pumps, temperature controllers, power factor equipment, vaccum cleaners, variable speed drives, fluorescent lights, inverters, compressors, motor controllers, are among items producing transients (Alltec,2019, Martina,1996, S3 Energy, 2019),

V. EFFECT OF TRANSIENT

- Malfunction and reduction of efficiency in electrical equipment
- Burning of integrated circuits (IC)
- Generation of heat and noise in electric motors
- Subjection of insulation to overvoltages results into wear and tear. In overhead lines, this may range from minor cracks to total damage. (Ezechukwu, 2013). According to ABB (2012), transients cause severe damages to the insulation of electric motors and lines mostly affected are 33kv and below for the fact that insulations of such lines are small and weak.
- The insulation designed for the windings of transformers and motors do not cover high transient voltage levels, hence, suffer from transients and related damages (Piasecki, Florkowski el tal nd)
- Transient result in increase in electric motor temperature and vibration (ABB, 2012)

- High currents associated with transients results into increase in hysteresis loss in electric motors due to overheating.
- Development of dark rings in fluorescent tube ends results into poor performance or outright failure.
- False tripping of circuit breakers and switches due to burning of contact points.
- About 35 percent of dielectric failure is traced to surges emanating from transients (Piasechi (nd,).
- Incandescent light failures are sometimes attributable to transients.
- Overvoltages from transient may rise above twice normal system voltage capable of destroying electronic items and reduction of equipment lifespan (Martina, 1996).
- Variable speed drives (VSDs); the effects of verying frequent switching accumulate over time, can contribute to insulation damage, since VSDs usually operate at kHz frequencies causing thousands of over-voltages per second which results in loss of integrity of the insulation. (ABB,2012)

VI. MITIGATION AGAINST TRANSIENT

Mitigation is to reduce the risk of loss from an unwanted event (Coleman, 2018). Various approaches are available to achieve the desired system reliability. Martzloff (2004) enumerated three approaches adopted in various ways;

- Conduction of surge current to ground.
- Blocking sources of transient
- Protection against direct effect

Protection against lightning effects include two categories: (1) direct effects concerned with the energy, heating, flash, and ignition of the lightning, (2) indirect effects concerned with induced overvoltages in nearby electrical and electronic systems (Altas,nd). In (Marzloff, 2004) shielding, bonding, and grounding are three interrelated methods for protecting a circuit from external transients.

- Suppressors in common use include: Metal Oxide Varistors (MOV) and electronic tracking types (Martina, 1996). The term varistors implies variable resistor that at low voltage across the varistor, only very little current flows. While, at higher voltages the resistance of the varistor drops dramatically. Fundamentally, it clamps certain voltage levels higher than the rms voltage value.
- Electronic suppressors track incoming sine waves and the clamping voltage which may be a fix value though higher than the instantaneous value of the sine wave. This device operates much faster than the Metal Oxide Varistor (MOV) (Martina 1996).
- For some applications, the diode based Transient Voltage Suppressor (TVS) shows clear advantage over the varistor in terms of protecting sensitive components from excess voltage (www.onsemi.com, nd).
- RC-circuits form a bypass for high frequency currents and voltages in that the transients are diverted to earth instead of reaching the equipment to be protected shown in figure 4 (Mueller and Saemann (nd)

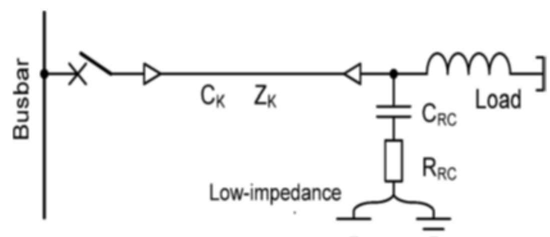

Figure 4; R-C circuit for mitigating transient. Source: Mueller and Saemann (nd)

In Mueller and Saemann (nd), surge arresters limit the transient overvoltage values in most applications; Arresters must limit the overvoltages between the phases (L-L) just as phase-to-earth (L-E). Three arresters connected to protect between phases in figure. 5 and in figure 6, six arresters are connected for phase-earth protection.

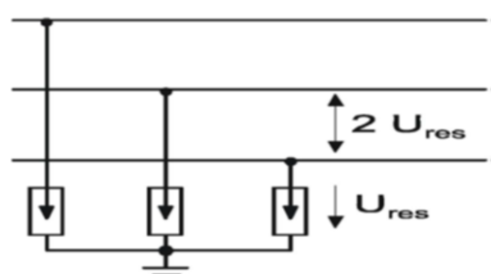

Figure 5. Three arresters to protect phase-Phase: Source Mueller and Saemann (nd)

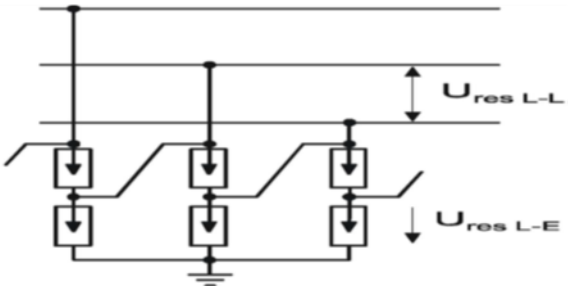

Figure 6, Six arresters connected to protect phase-earth. Source: Mueller and Saemann (nd).

Surge capacitors are used to reduce the rate-of-rise of surges by increasing the line-earth capacitance, particularly, to protect transformer secondary terminals against transients' voltages from the primary side (Mueller and Saemann ,nd).

Electro flow: This device controls the surge as well as protecting devices connected to it illustrated in figure 7

Figure 7. Electro flow. Source: Electrical Engineering Community (2013)

- Magnetic relays are employed to block transients in distribution systems.
- High frequency resonators when used in gas insulated stations damps transients (Riechert,2012)
- In Burow (2012), synchronous controlled switching is capable of reducing oscillatory transient overvoltages.
- Environmental potential (EP); EP2000 equipment when used with electrical equipment mitigates the effect of transients by removing electrical noise and suppress voltage transients generated from turning relays on and off (Environmental Potentials ,2009)
- Installation of opening and closing resistor decreases both amplitude and steepness of transient overvoltages (Ram and Swaraj, 2012)
- Speed control in generator: generator

produces voltage equal Blv, expressed as:

$$V = Blv \qquad (5)$$

Where V= voltage, B= flux density, v= velocity hence, an increase in generator speed correspondingly increases its voltage, Ezechukwu (2013). But, a generator equipped with automatic speed control can reduce the effect of transient. Again, injecting more inductance to a line reduces transient due to capacitance and adding more loads or line compensators equally reduces the power generation arising from switching transients.

- Sub-transient fault may be mitigated by using reclosers.
- Distribution transformer windings must be designed to withstand transient impulses, particularly for installation in areas prone to atmospheric discharges and protected by spark gap. To achieve better results, the winding design should include electrostatic screen components in order to equalize voltage distribution.
- For power lines, lightning arresters can reduce the effect of transient The use of electromagnetic high-frequency resonators designed to operate on a range of frequencies can dissipate the energy contain in the transient induced overvoltage. The radio frequency resonator once tuned to the salient harmonic result in damping transient effect proved experimentally (Burow, el tal 2012)
- A series–impedance and shunt capacitor protection termed smart-choke provides impedance - frequency behavior which reduces the dv/dt to a safe level while eliminating high frequency oscillation, thus, acting as low-pass filter. According to Piasecki (nd), the smart choke when combined with transformer busing ensure adequate filtering of the dv/dt transient, hence, protecting the windings from transient caused overvoltages, illustrated in figure 8

Smart-choke

Figure 8. Smart Choke element integrated within a transformer. Source: Piasecki (nd).

- In Ezechukwu (2013), circuits involving resistance, inductance and capacitor with large values and complex, expressed as;

$$LC : I(s)= \frac{A}{S2 + Xs + y} \quad (6)$$

Where x = R/L, y = 1/LC and A = the numerator, V/L

Ezechukwu's reduction formula may be used to achieve damping of transient conditions, from equation (6) expressed as:

$$I(s)\frac{\sqrt{(y-\frac{x^2}{4})}}{(s+\frac{\lambda}{2})^2+(\sqrt{\frac{y-x^2}{4}})^2}\left(\frac{A}{\sqrt{\frac{y-x^2}{4}}}\right) \quad (7))$$

VII. RESULTS AND DISCUSSION

The review reveals that most sources of disturbances within the electrical/electronic systems previously difficult to pinpoint are now traced to a phenomenon termed transient. It is periodic and capable of producing harmonics, overcurrent and overvoltage from lightning, switching and internally generated sources.

Destructive effects highlighted and the mitigating methods are for implementation by equipment designers, manufacturers' and users to ensure reliability. Various figures were also employed to illustrate varying transient conditions.

In figure 1, the transient system shows current and frequency surges capable of causing destruction to electrical/electronic equipment. Rise in current during lightning strike and its associated time without continuing current in figure 2a. This scenario is usually recorded from direct lightning strike, though, less destructive. While, in figure 2b, depict a more dangerous trend as it carries bulk of the energy from lightning from cloud to ground due to the presence of continuous current. It involves conductive medium creating high electromagnetic effects.

Figure 3, clearly demonstrated an induced voltage arising from transient during lightning strikes. That the severity depends on the distance between the striking point and equipment, hence, an increase in distance implies less impact. An R-C circuit shown in figure 4 is to limit transient overvoltage. Similarly, figures 5 shows three arresters connected to protect phase-phase faults and in figure 6, six arresters are connected to protect phase-earth disturbances. In figure 7, the device performs several functions, such as receiving transient, modifies and supplies the desired alternating current into the protected equipment for proper functioning. Figure 8, is simply termed the smart-choke circuit which is a combination of a series – impedance and shunt capacitor circuit connected to transformer bushing to function as low –pass filter for protection of transformer winding from the negative effects of transient.

The study therefore focuses on proper selection of equipment and that of an appropriate protective device as applied to electrical/electronic equipment.

CONCLUSION

Causes, effects and mitigation of transients in electrical power systems were reviewed in this paper. Transient appear as disturbance, giving rise to harmonics, overcurrent and overvoltage, consequently damages electrical/electronic equipment, cables, dielectric failure, power outage, flashover amongst others.

Common causes of transient in electrical systems include lightning (external) and switching (internal). It is important for owners of equipment connected to electrical power systems to appropriately protect them from being damaged by transients.

Mitigating methods involving suppressors, blocking or clamping and conduction techniques were highlighted in this paper which when applied correctly can prevent or reduce the harmful effects of transients, fundamentally, to secure equipment service continuity and reliability in order to achieve low operational, maintenance and replacement costs.

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