CONVERTING SOLIDILY GROUNDED TRANSFORMERS TO HIGH RESISTANCE GROUNED SYSTEMS; PRACTICAL APPLICATIONS STUDY

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***Abstract* - This paper is a summary of a case study of a pulp and paper mill that had greater than 100 solidly grounded substations. In order to reduce the likelihood of an arc flash, they were changes to a high resistance grounded system. This change increased the safety and reliability of the facility as well as reduce arc flash incidences in the low-voltage substations.**

Index Terms – High resistance grounding, arc flash mitigation, system grounding.

I. Introduction

There are many ways to mitigate arc flash energy and incidences. NFPA 70E states: [1].

"**O.2.1** Employers, facility owners, and managers who have responsibility for facilities and installations having electrical energy as a potential hazard to employees and other personnel should ensure that electrical hazards risk assessments are performed during the design of electrical systems and installations."

From the onset of any power distribution project, arc flash design discussions should first focus on how to best protect the employees while limiting the fault currents to reduce arc flash incident energy. To maximize the advantages of mitigation techniques, one should employ a combination of techniques concurrently while also limiting the probability of occurrence utilizing High Resistance Grounding.

The following well-recognized methods should be considered to facilitate the reduction of arch flash hazards:

(1) Achieve an electrically safe work condition.

(2) Reduce the likelihood of exposure through the use of High Resistance Grounding

(3) Reduce the magnitude of the arc flash through several well-recognized mitigation techniques such as relay coordination changes and equipment changes,

(4) Reduce the severity of exposure through the use of the proper personnel protective equipment.

This paper will discuss what strategies were employed as well as what can be done in the future to mitigate hazards further. This paper will be limited to the low-voltage system only.

Per IEEE 1584[2] it is necessary to evaluate the arc flash mitigation utilizing the following two equations:

Equation (1) shows the calculations required to solve for the arcing current

$$\lg I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526G + 0.5588V(\lg I_{bf}) - 0.00304G(\lg I_{bf})$$

Where

lg	is the $\log_{10}$
I_a	is the arcing current (kA)
K	is -0.153 for open configurations is -0.097 for box configurations
I_{bf}	is bolted fault current for three-phase faults (kA)
V	is the system voltage (kV)
G	is the gap between conductors, (mm)

Equation (2) is used to determine the normalized incident energy.

$$\lg E_n = K_1 + K_2 + 1.081 \lg I_a + 0.0011G$$

Where

E_n	is Incident Energy (J/cm^2) normalized for time and distance
K_1	is -0.792 for open configuration Is -0.555 for box configuration
K_2	is 0 for ungrounded and high resistance grounded Is -0.113 for solidly grounded

Finally equation (3) is used to determine the incident energy at a distance and set time.

$$E = 4.184 C_f E_n \left(\frac{t}{0.2}\right)\left(\frac{610^x}{D^x}\right)$$

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Where

E	is Incident Energy (J/cm^2)
C_f	is calculation factor (1.5 for Low-voltage)
t	is arcing time (s)
D	distance from the possible arc point to the person (mm)
x	is the distance exponent.

II. Reducing the Probability of Exposure

The first step in addressing arc flash is to reduce the probability of exposure at the inception of the arc fault. This can be accomplished utilizing high resistance grounding (HRG) systems

A. High Resistance Grounding

It is well known that up to 70% of all electrical faults begin as single-phase-to-ground faults. [3] Therefore, reducing the energy produced by this type of fault will reduce the likelihood of a single phase to ground fault to propagate to a phase to phase or 3 phase fault, thus reducing the likelihood.

Annex O of NFPA 70E clearly specifies high resistance grounding as an arc flash mitigation technique. Yet, in looking at equations1, 2, and 3, it is easy to determine that the act of employing a high resistance grounded system will not lower incident energy, but increase it, so why would NFPA 70E reference HRG installations as a method to mitigate arc flash hazards? The reason is that installing HRG systems reduces the probability of the most common type of fault (Phase to ground) being limited in energy to propagate to a phase to phase or three phase fault.

High resistance grounding is the only method to date that will reduce the probability of exposure before a significant phase to ground fault arc flash occurs. The methods that will be briefly discussed will not reduce the probability of an arc flash occurring, and begin mitigating the arc flash only after the fault has occurred.

In the studied facility, a significant decision-making process was conducted to determine the best approach which gave the facility the most protection for their employees. To do this, the owners chose to implement arc flash reduction in a two-pronged attack; first limit the probability of arc flash occurring and second reduce the arc flash incident energy if more than a phase to ground occurs. Arc flash mitigation was accomplished through a number of strategies;

Reduce probability of Arc Flash:

1) High Resistance Grounds Systems were installed on all low-voltage transformers

Reduce Arc Flash Incident energy:

1) Installation of low-voltage power circuit breakers (LVPCB) digital relays on most (low-voltage (LV) breakers for tighter tripping control.
2) Installation of electronic protection relays on low-voltage substations which incorporated Maintenance Mode switches programmed into the relays
3) Installation of C200 class CTs to serve the new digital relays
4) Installation of 15kv primary fuses which have faster trip curves.

Many substations were converted from solidly grounded to high resistance grounded. With disadvantages and advantages as follows:

HRG Disadvantages:
Per their study, the installation of these HRG systems did in fact increase the arc flash incident energy somewhat. They found that several substations went from Category 4 to Category Dangerous. This necessitated more remote trip installations and equipment.

The facility also recognized another disadvantage; the unavailability of the neutrals to service line-to-neutral loads. This necessitated the installation of isolation transformers to service these loads. This also made the system safer by exposing the single phase loads to much lower bolted fault current.

HRG Advantages:
Even with the added cost to the project, there where overwhelming advantages observed by utilizing a high resistance ground system and the facility felt it was well worth it since they wanted to not only reduce the probability of an arc flash occurrence but also reduce the incident energy to protect their employees.

1) With the HRG systems installed, the facility saw continuity of power even during the presence of a phase to ground fault. This kept the operations running and gave them the time needed to swap to a backup motor / system and not disrupt the operation.

2) An unexpected advantage observed was the decrease in motor failures as represented Fig. 1 which directly correlated to the reduction of operational LV electrical downtime and in increase in the facility reliability. This was significant cost avoidance for the operation.

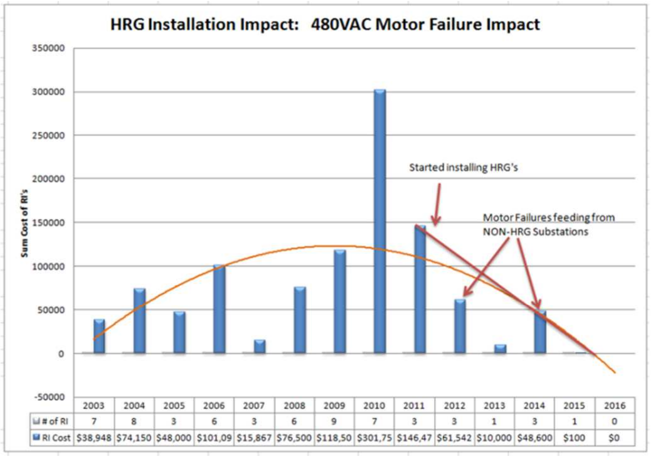

Figure 1 Motor Repair costs. [4]

Shown in Figure 1 are the repair costs of the motors. It can be seen that the trend prior to the installation of the HRG is increasing in cost. After installation of the HRG systems both the frequency of motor repair and the costs of motor repair have decreased.

III. Conclusion

The initial state of the facility substations were solidly grounded with some of them having an incident energy of 36 cal/cm^2 . NFPA 70 E states that high resistance grounding is an arc flash mitigation technique, but, after its implementation the incident energy increased to 47 cal/cm^2 which was further mitigated using zone-selective interlocking and other methods.

Although the incident energy increased on the substations where HRG's were installed, when combined with other well accepted technical arc flash mitigation strategies the facility considered the combination much safer and less risk to the operational continuity than implementing a single arc flash mitigation element.

By integrating HRG's as suggested in NFPA 70E, we have an arc flash mitigation technique that reduces the likelihood of an arc flash occurring.

NFPA suggests many techniques to mitigate arc flash hazards. By far one of the most effective and the only method that works before the fault occurs is high resistance grounding. This method combined with other mitigation strategies will increase operational uptime as well as reduce arc flash incident energy levels.

IV. Refrences

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V. Vita

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