

Geomagnetic Induced Current (GIC) Mitigation System Summary for the White Paper

Grounding of power grids provides benefits to improve AC operation and to optimize the economics of transmission network design. The primary benefits have been control of overvoltages, improved sensitivity to system events, faster breaker operating time, and selectivity of ground fault relaying. The industry's approach over many decades has been to apply the blanket assumption that ground is an infinite sink. However, it should be realized that ground during a geomagnetic storm becomes a source that injects currents into the transmission network. Grounding methods of the transmission network allow the influences of geomagnetic storms, which are chiefly quasi-dc currents to migrate into the transmission grid. This can produce two deleterious effects on the transmission system due to half-cycle saturation of EHV transmission-connected transformers. One effect is the possible overheating of transformer components due to over excitation. The other effect is distortion of the 60 Hz power and exciting current which results in increased var loading and harmonics. Since both of these effects are related to the flow of quasi-DC currents in transformer neutrals, it is reasonable to examine methods of mitigation..

There are several GIC filter designs and strategies. These can be classified into two major categories. The first are series capacitor banks, which are primarily used for series compensation of transmission lines, but have a secondary effect of blocking dc current flow in transmission lines. Series capacitors are costly, and are usually applied to improve system stability.; therefore, dc blocking is a secondary benefit not a primary application at present. Series capacitor banks are a mature and reliable device covered by IEEE standard 824. The second category employs a transformer neutral current mitigation scheme. Such devices have been installed on a limited basis. Consequently, these systems do not have extensive operating histories and have been, for the most, part custom engineered on a case-by-case basis.

The neutral current blocking devices are designed to block or impede the flow of GIC (Quasi-dc) where the current couples to the power system. Neutral blocking philosophy has been researched and tested by EPRI. The testing consisted of computer simulations, laboratory prototypes, and in actual full scale projects installed at Minnesota Power. These EPRI projects, documented in reports EL-3295 (December 1983) and TR-100450 (June 1992), demonstrated the viability of neutral blocking devices for mitigating the effects of GIC. In addition, similar transformer neutral devices have been installed elsewhere in the industry for GIC mitigation and other operational conditions.

The above mentioned tests employed criteria which, under today's system conditions, were less stringent than some system conditions require today. Therefore, as neutral blocking designs are developed they should incorporate functionality that meets a

uniform set of criteria, such as fault currents up to 30,000 amps and 200 amps AC neutral imbalance current, in order to perform under a wide variety of system configurations. If a manufacturer's design of a blocking system should indicate economic benefits from having a range of ratings from which to choose to meet a specific installation, then such options should be considered.

Some transformer designs may be more susceptible to damage caused by GIC currents. Installing mitigation devices in the transformer neutral can protect the transformer and system by blocking, reducing, or mitigating the effect of potentially harmful GIC currents. The mitigation devices will benefit the electrical transmission system by preventing excessive var consumption and harmonic currents caused by half-cycle saturation in large transformers.

Installing an impedance in the neutral of a transformer can pose problems that can affect transformer reliability and safety. Typical transformer insulation systems are originally designed as solidly-grounded wye systems. These designs typically incorporate a reduced transformer neutral BIL rating. Inserting an impedance in the neutral connection can create voltage levels which exceed the transformer neutral BIL rating. Therefore, inserting an impedance in the neutral to ground connection poses engineering challenges must account for and limit over voltages at the neutral and phases for the full range of operating conditions (including, but not limited to: through faults, load imbalances, TRV events, excessive 3rd harmonics, lightning, internal faults, bolted faults, circulating currents, ferro-resonance, etc).

Other GIC mitigation philosophies may be developed as the demand and knowledge grows regarding the protection of the power system against GIC disturbances. It is not the intent to limit discussion to blocking or reducing systems, nor to infer they are the only solution. Some systems may be developed to harness the energy of a GMD or allow the GICs to flow, controlling the influence on the power system. Regardless, the devices or equipment installed on the system must adhere to a minimum set of standards and have a desirable set of characteristics.

GMDTF queried known GIC mitigation device vendors for details of their devices. Four vendors responded with a set of attributes (appendices 1 to 4):

1. GIC Reducer – Dr. Ramirez-Orquin Appendix A
2. SOLIDGROUND™ Neutral DC Blocking System – Emprimus LLC Appendix B
3. Neutral Blocking and Bypass Device (NBBD) – Phoenix Electric Co Appendix C
and Advanced Fusion Systems LLC.
4. Active Ground Device (AGD) – Advanced Fusion Systems LLC Appendix D

The Table below is brief assessments of submitted vendor solutions against an eleven point Criteria

Criteria/Suppliers	GIC Reducer	Emprimus SolidGround™	AFS NBBD	AFS Active Gnd Device
<p>1. Fail Safe – does the system continuously maintain a grounded neutral</p>	<p>Yes, only possibility of not having a grounded neutral exists if the MOV unit (2 surge arrestors) fail open. Vendor assumes arrestor fail shorted. If both arrestors fail open the resistor is unprotected for the next fault and manual bypass must be closed or transformer outaged. Client could go, with minor size/cost impact, to a Bank with (n+1) staged-rated arresters; n being the number of reclosing attempts (or similar criteria). With multiple arrestors losing ground becomes extremely unlikely.</p>	<p>Yes, only possibility of not having a grounded neutral exists if the MOV surge arrestor fails open and the ground switch fails to close. With fault current through the arrestor the high speed ground switch is closed. The neutral ground is provided 100% of the time either through the switch assembly or through a capacitor bank.</p>	<p>Yes, only possibility of not having a grounded neutral exists if the electron tube fails open and the bypass breaker fails to close. This will leave the capacitor unprotected for the next fault.</p>	<p>Yes, only possibility of not having a grounded neutral exists if the Active Ground Device fails open. AGD has a high degree of robustness and MTBF. Specific data is available under an NDA.</p>
<p>2. Cannot create any resonance conditions</p>	<p>No resonance issues for resistor only application</p>	<p>Any resonance is dampened with the one ohm resistor in series with the one ohm capacitor. Additionally, the MOV significantly reduces any</p>	<p>Per EPRI/IEEE paper and field tests none observed. Vendor claims electron tube speed can dampen any resonance</p>	<p>Device is not capacitive, no resonance issues</p>

		resonances.		
3. Insertion cannot change system characteristics	Increases ground fault impedance. Vendor indicates less than <5% increase in overvoltage	There is minimal change to the system characteristics. And the neutral is grounded directly through switches 99.8% of the time.	Capacitor decreases ground fault impedance. Vendor claims no degradation on system fault performance	Reduces fault current levels, will require relay setting changes
4. Must be maintainable – removed and re-inserted without transformer outage	Vendor claims maintenance free to be maintained at the time of transformer maintenance. Maintenance at other times will require a transformer outage	Yes, AC ground switch assembly is closed to provide a grounded neutral to allow operation of separate maintenance grounding switches to isolate the neutral system.	Yes, Bypass breaker is closed to provide a grounded neutral to allow operation of separate maintenance grounding switches to isolate the neutral system.	Maintenance switches are a recommended addition by the Client
5. The system handles unbalance of 200 amps – insertion and removal without transformer outage	Vendor or Client supplied ground switches will need to be specified to cover 200A AC breaking in order to have load break capability, unless transformer outages are taken	Yes, the mitigation system is designed to handle a 200A unbalanced current. The answer to this criteria is the same as the answer above for criteria #4.	Yes, the mitigation system is designed to handle 200A unbalanced current. The bypass breaker is closed to permit operation of maintenance switches to insert or remove the mitigation system under 200A neutral AC.	States the mitigation device can handle 200A
6. The system handles insertion under GIC conditions	Vendor or Client supplied ground switches will need to be specified to cover 100A DC breaking in to have GIC break capability, unless transformer outages are taken.	Yes, but no insertion is required for the SOLIDGROUND solution. The system always has the blocking capacitor bank connected to ground. The switch assembly only shorts out	Uncertain on the DC interrupt capability of the bypass breaker and capability of opening the isolation switches under 100A GIC	Is expected to be in service at all times

		the capacitor bank when a GIC is not present.		
7. The system must be able to withstand full range of operating conditions	Mitigation system will have to be evaluated against environmental and power system conditions for the locations looking to apply the mitigation solution.	Mitigation system will have to be evaluated against environmental and power system conditions for the locations looking to apply the mitigation solution.	Mitigation system will have to be evaluated against environmental and power system conditions for the locations looking to apply the mitigation solution.	Mitigation system will have to be evaluated against environmental and power system conditions for the locations looking to apply the mitigation solution.
8. The system must be remote controllable with automatic sensing and insertion capabilities	Not recommended by the vendor for continuous operation – no remote control nor automatic sensing and insertion provide be the vendor. Client has option for ground-switch remote control.	Yes, remote control capability is provided. The mitigation system provides automatic operation from selectable GIC current or harmonic levels. The removal must be operator initiated and is performed remotely.	Vendor envisions mitigation system is service all the time. Any remote control or automatic sensing and insertion provide by customer.	In service at all times
9. The system must be periodically tested	No remote capability for insertion for periodic testing. Optional; only if client deems necessary functionality on this simple ground resistor insertion device.	Yes, remote control capability is provided for an operator insertion and removal of the mitigation system remotely at any and all times.	Testing is available at the discretion of the Client.	Testing is available at the discretion of the Client
10. The system must have some form of self diagnostics for knowledge mitigation device or	None – vendor indicate optional surge arrester electrical monitoring.	The operator can test as frequently as required. Operation of a Lockout relay would indicate pressure relief operation of the MOV surge	Self diagnostics is available at the discretion of the Client.	Self diagnostics is available at the discretion of the Client.

bypass failure		arrestor.		
11. The system must meet all applicable standards	Vendor proclaimed meeting of the team's prescribed list.	Vendor proclaimed meeting of the team's prescribed list.	Vendor proclaimed meeting of the team's prescribed list.	Vendor proclaimed meeting of the team's prescribed list.

Although the GMDTF finds that for each mitigation system reviewed, successful operation to block or reduce GIC effect is possible. We also find there are many concerns regarding practical operation of mitigation systems. These concerns should be addressed by additional simulation, component validation, full-scale testing, field installation and additional information from the vendor concerning detailed operation of their system.

A properly designed GIC blocking system should greatly improve system reliability under a GIC event. However, a major concern is the successful operation of a bypass device to the current limiting component during a system fault condition. Mis-operation of a bypass device could cause major system issues and failure of key system components, including insulation failure of the transformer. Thus, producing the undesirable effect of compromising the reliability of the transmission system. Operation of the various GIC mitigation devices under the full range of environmental and system conditions cannot be fully assessed based on the submitted information. Any design should incorporate a safeguard to handle any and all operating conditions including faults.

Mitigation systems will be essential to reduce GIC reliability risks for certain geographic locations and level of GMD events. The application of each single mitigation device may pose a singular risk to the particular connected equipment. Each mitigation system application will need its own risk assessment based on type of mitigation device, modes of operation and characteristics of the equipment the mitigation device is connected to.

Sufficient study, research, development and testing are required to validate that any of the currently proposed systems or any future systems are viable.