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UTILIZATION OF THIRD HARMONIC RATIO STATOR GROUND FAULT PROTECTION AND STATOR GROUND FAULT PROTECTION WITH REDUNDANT 20 HZ VOLTAGE INJECTION FOR RELIABLE STATOR GROUNDING PROTECTION ON GENERATOR NEUTRAL SIDE FOR GROUND CONTROL SYSTEM OPERATION APPLICATION IN DRONE FLIGHT

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***ABSTRAK* — *This study aims to determine the advantages and disadvantages of using the type of stator grounding fault protection using voltage injection and traditional. As we know there are many types of protection for stator grounding faults on the neutral side of the traditional ones such as neutral overvoltage and using the 3rd harmonic ratio voltage ratio between the generator terminal and the neutral side, this traditional method has some problems in sensitivity, safety and cleaning speed, in the long run can make low-level grounding faults become damaging disturbances. And now we already have the latest method for stator grounding faults, using 20Hz voltage injection which can reduce the problems in the traditional ones. The only problem with 20Hz voltage injection is the voltage injector device, if this device has some problems, then the protection cannot operate. This paper wants to explain the advantages of traditional protection (3rd harmonic ratio stator grounding protection) and stator grounding protection with 20Hz voltage injection installed redundantly, then the stator grounding protection on the neutral side of the generator will be more reliable.*

***Keywords**: harmonic, protection, stator, redundant, redundant.*

***ABSTRAK* —** Penelitian ini bertujuan untuk mengetahui keuntungan dan kerugian menggunakan jenis proteksi gangguan pentanahan stator dengan menggunakan injeksi tegangan dan tradisional. Seperti yang kita ketahui banyak jenis proteksi untuk gangguan pentanahan stator pada sisi netral dari yang tradisional seperti tegangan lebih netral dan menggunakan rasio tegangan rasio harmonik ke-3 antara terminal generator dan sisi netral, metode tradisional ini memiliki beberapa masalah pada sensitivitas, keamanan dan kecepatan pembersihan, dalam jangka panjang dapat membuat gangguan pentanahan tingkat rendah menjadi gangguan yang merusak. Dan sekarang kita sudah memiliki metode terbaru untuk gangguan pentanahan stator, menggunakan injeksi tegangan 20Hz yang dapat mengurangi masalah pada yang tradisional. Satu-satunya masalah pada injeksi tegangan 20Hz adalah perangkat injektor tegangan, jika perangkat ini memiliki beberapa masalah, maka proteksi tidak dapat beroperasi. Makalah ini ingin menjelaskan keuntungan dari proteksi tradisional (proteksi pentanahan stator rasio harmonik ke-3) dan proteksi pentanahan stator dengan injeksi tegangan 20Hz yang dipasang secara redundan, maka proteksi pentanahan stator pada sisi netral generator akan lebih andal.

Kata kunci: harmonik, proteksi, stator, redundan, andal

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1. *INTRODUCTION*

Generator is the most important electrical equipment in the power plant existence it's make so many protection installed to protect it from the fault. As we know the fundamental protection like differential current protection, overcurrent protection, and etc. there's some occurrence in generator like decreasing of the insulation value cause of aging. usually due to it occurrence the fundamental protection can't detect minor fault, however the minor fault can become major fault and make generator damaged. There's so many subsidiary protection that can detect minor fault but in this paper we only focusing on stator grounding protection especially in generator neutral side.

1.1. 3rd harmonic in the generator

Presence of third harmonic voltage at the generator neutral and its terminal can be considered as a sign of generator health, with no presence of stator grounding fault near either the neutral or the terminal. The 3rd harmonic current will flow from the generator phases to ground via the capacitances of the stator, ISO-phase buses, surge capacitor, and transformer windings and back through the generator neutral. The 3rd harmonic voltage is produced by nonlinearity within the generator (Mohamed A. Ibrahim, 2012). When the generator is healthy (no stator grounding fault). The 3rd harmonic voltage will cause circulation of 3rd harmonic currents around the generator. This will result in 3rd harmonic voltage appearing across the generator neutral grounding resistor connected to the secondary winding of the distribution transformer between the neutral of the generator and ground. The value of voltage will depend on many factor.

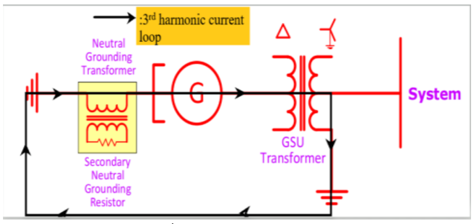

Fig 1. 3rd harmonic current loop

1.2. 20 Hz voltage injection

Via injecting 20 Hz voltage, the protection can judge whether a ground fault happens at the circuit of generator stator winding side, it can detect single phase ground fault of 100% of the stator winding. Generator stator grounding fault protection (with 20Hz voltage injection) will not be affected by generator operation condition, even during shutdown condition, the protection still can be monitoring the insulation condition of the stator winding.

2. *METHODHOLOGY*

Methodology in this paper using study literature and observation on the actual equipment. Fortunately author is a relay protection technician in steam power plant company, so author using his experience when conduct comissioning, FAT (Factory Acceptance Test), and overhaul also combining with study literature from manufacture manual book.

3. *RESULTS AND DISCUSSION*

3.1. 3rdharmonic ratio stator grounding fault protection.

Fundamental zero sequence voltage stator ground fault protection can only detect the ground fault of 85%-95% of stator winding of generator terminal side, for the ground fault that near the neutral point, it can be detected by3rd harmonic ratio stator grounding fault protection. 3rd harmonic ratio stator ground fault element. It can detect the ground fault approximately 25% of stator winding of generator neutral point side. Generator 3rd harmonic stator *grounding fault protection includes two operation elements: 3rd harmonic ratio stator grounding fault element and 3rd harmonic differential stator grounding element. Fundamental zero sequence voltage stator grounding fault protection coordinate with 3rd harmonic ratio stator ground fault element can constitute 100% stator ground fault protection. 3rd harmonic differential stator ground fault element can reflect the ground fault of the whole stator winding, but it's very sensitive, so generally it's only alarm. The calculation process of 3rd harmonic stator grounding fault protection is shown in following figure 2. The generator neutral point is grounded via grounding transformer, it can also be grounded via grounding VT. When the ground fault happens at the generator stator winding the distribution of the circuit ground capacitance will be change, by detecting the 3rd harmonic zero sequence voltage of generator terminal and neutral point, the device can judge whether a stator ground fault happens.*

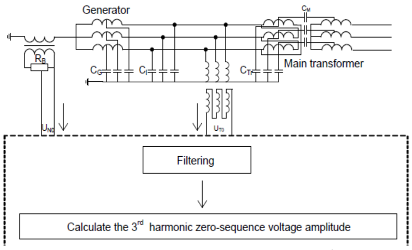

Fig 2. Calculation process of generator 3rd harmonic stator ground fault protection Where:

- *RB is the secondary load resistance of neutral point grounding transformer;*
- *UN0 is the tap voltage (it's 100V or 173V generally) of secondary load resistance of neutral point grounding transformer;*
- *UT0 is the broken delta zero sequence voltage of generator terminal VT;*
- *CG is the generator stator winding ground capacitance;*
- *CI is the ground capacitance of the outgoing line of generator terminal;*
- *CTr is the main transformer ground capacitance;*
- *CM is the coupling capacitance between the HV winding and LV winding of main transformer.*

3.2. 3rdHarmonic Ratio Stator Ground Fault Element

3rd harmonic ratio stator ground fault element can only detect the ground fault of approximately 25% of stator winding of generator neutral point side, generator terminal 3rd harmonic voltage is derived from generator terminal broken delta zero sequence voltage or calculated zero sequence voltage of VT1, generator neutral point side 3rd harmonic voltage is derived from generator neutral point VT or the tap voltage of load resistance of grounding transformer. The operation criterion of 3rd harmonic ratio stator grounding fault element is:

$$U_{3T} / U_{3N} > K_{3WZD} \text{............(1)}$$

Where:

- *U_{3T} and U_{3N} are 3rd harmonic voltage value of generator terminal and neutral point respectively;*
- *K_{3WZD} is the ratio setting of 3rd harmonic ratio stator grounding fault element.*

Generator terminal equivalent capacitance has a greater chance before and after the unit is connected with the power grid , so the 3rd harmonic voltage ratio will change with it. So two different ratio setting are configured for the 3rd harmonic ratio stator ground fault element respectively for the condition before and after the unit is connected with the power grid, the two setting are switched over automatically with the position contact change of the generator terminal circuit breaker. For 3rd harmonic voltage has close relationship with the generator operating condition, so3rd harmonic ratio stator ground fault element is only enabled when the generator positive-sequence voltage are respectively larger than a certain threshold value. If the generator frequency shifts near the power frequency, the ratio setting will add a frequency additional restraint threshold. If *the generator frequency seriously deviated from the power frequency, 3rd harmonic ratio stator ground fault element will quit automatically. The 3rd harmonic ratio stator ground fault element can operate to trip or alarm.*

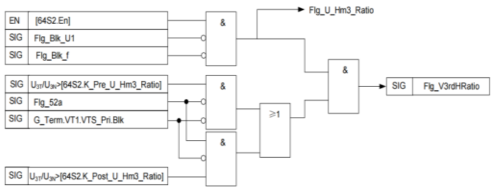

Fig 3. Logic diagram of 3rdHarmonic Ratio Stator Ground Fault protection

- *[64S2.En] is enabling protection logic setting Flg_Blk_U1 is the terminal signal indicating that the generator positive sequence voltage is lower than a certain threshold value.*
- *Flg_Blk_f is the internal signal indicating that the generator frequency is seriously deviates from the power frequency.*
- *U_{3T}/U_{3N} >[64S2.K_Pre_U_Hm3_Ratio] is the actual 3rd harmonic ratio exceed from pre-sync (to the grid) setting value.*
- *Flg_52a is the internal signal indicating that the generator unit is connected with the power grid.*
- *G_Term.VT1.VTS_Pri.Blk is generator terminal VT1 primary circuit failure blocking input.*
- *U3T/U3N>[64S2.K_Post_U_Hm3_Ratio] is the actual 3rd harmonic ratio exceed from post-sync (to the grid) setting value.*

3.3. Generator Stator Ground Fault Protection with 20 Hz Voltage Injection

Generator stator ground fault protection (with 20Hz voltage injection) that use resistance criterion: it can detect single-phase ground fault of 100% of the stator winding. Generator stator ground fault protection (with 20Hz voltage injection) that use zero sequence current criterion: it's used to detect single-phase ground fault of 80%-90% of stator winding of generator terminal. The external low frequency power supply is injected to generator neutral point, the amplitude of the injected voltage is about 1%-3% of the generator rated voltage (depend on neutral grounding transformer ratio). The device measures the injected voltage and current, then calculate the transition resistance of a ground fault. If no single-phase ground fault happens, the injected current is mainly capacitive current, when a single-phase ground fault happens, the calculated grounding resistance value will decrease or the zero-sequence current will increase. Generator stator ground fault protection (with 20 Hz voltage injection) includes two operation elements: grounding resistance criterion element and zero sequence current criterion element. The calculation process of generator stator ground fault protection with 20Hz voltage injection is shown as below. In the figure 4 generator neutral point is grounding via a grounding transformer. If a ground fault happens at the generator stator winding, generally the injected low-frequency voltage will decrease and the low-frequency current will increase. If the ground fault location is not near to the neutral point, the zero-sequence current will increase significantly. The device detect the injected low-frequency voltage and current, the ground fault transition resistance value can be calculated after compensation (all the compensation parameters should adopt the actual measured value in the compensation test when the generator is at rest). The device detecting the neutral point grounding current and calculate the zero-sequence current , in order to improve reliability of zero-sequence current criterion element, zero-sequence current criterion element can be blocked by the generator terminal zero-sequence voltage or main transformer HV side zero-sequence voltage.

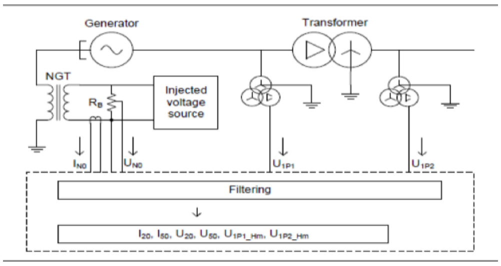

Fig 4. Calculation process of stator ground fault protection with 20Hz voltage injection

Where:

- *NGT is the neutral point grounding transformer;*
- *R_B is the secondary load resistance of neutral point grounding transformer;*
- *U_{N0} is the tap voltage of secondary load resistance of neutral point grounding transformer;*
- *I_{N0} is the secondary winding current of neutral point grounding transformer;*
- *U_{20} is the injected low-frequency voltage;*
- *U_{50} is power frequency voltage;*
- *I_{20} is the injected low-frequency current;*
- *I_{50} is the power frequency current;*
- *U_{1P1} is generator terminal zero-sequence voltage;*
- *U_{1P1_Hm} is generator terminal zero-sequence voltage fundamental component;*
- *U_{1P2} is main transformer HV side zero-sequence voltage;*
- *U_{1P2_Hm} is main transformer HV side zero-sequence voltage fundamental component.*

Grounding Resistance Criterion Element
The device can measure injected low-frequency voltage U20 and the injected low-frequency current I20, then the ground transition resistance Rg can be calculated after filter algorithm. Two stages are equipped for grounding resistance criterion element, the high-setting stage is used for alarm and low-setting stage is used for tripping with a time delay. The equation is:

$$R_g < R_{Alm} \ldots\ldots\ldots (2)$$

$$R_g < R_{Trp} \ldots\ldots\ldots (3)$$

Where:

- *R_g is the calculated ground transition resistance value.*
- *R_{Trp} is the resistance setting for low-setting stage (i.e. the tripping stage)*
- *R_{Alm} is resistance setting for high-setting stage (i.e. the alarm stage)*

The low-setting stage of grounding resistance criterion element will be blocked by the safely ground current setting, i.e. the tripping stage of grounding resistance criterion element can operate only when the grounding fault current exceeds the safely ground current setting. For example, after the shutdown of a generator unit, the grounding switch if the generator circuit breaker should be closed according to the operational procedure, for this moment, generator stator ground fault protection (with 20Hz voltage injection) only need to alarm without trip. If a ground fault happens near the neutral point for a operating generator, the grounding current is small and not larger than the safely ground current setting, then generator stator ground fault protection (with 20Hz voltage injection) has no need trip. If the setting [64SInj.En_Freq_Blk] is set as “0”, grounding resistance criterion element will operate during the whole frequency range; if the setting [64SInj.En_Freq_Blk] is set as “1”. Grounding resistance criterion element will be blocked during the frequency range of 10Hz-40Hz. Low-frequency zero sequence voltage signal will generate during the startup and shutdown of the generator, the signal maybe interfere the 20Hz injected voltage signal, then it will lead the measuring error of measured grounding resistance and the mal-operation of grounding resistance criterion element, so grounding resistance criterion element should be blocked during the frequency range 10Hz-40Hz. The device calculates the grounding resistance value according to the measure low-frequency voltage U20 *and the measured low-frequency current I20, the relationship between the calculated value and the actual stator grounding resistance value depends on the ratio of neutral point transformer, the ratio of the miniature CT and the voltage-divide ratio of the potentiometer. The calculation of the grounding resistance converting coefficient setting [64SInj.k_R] is as follows:*

$$[64SInj.k\_R] = (U_{tr}^2 * n_v) / n_a \quad ....(4)$$

Where:

- *Utr2 is the square of the ratio of neutral point transformer;*
- *nv is the voltage-divide ratio of the load resistance potentiometer;*
- *na is the ratio of the miniature CT of the measured circuit.*
- *The parameter error of the above equation is inevitable, it need to be fine- tuned through primary side resistance ground test.*

Zero -sequence Current Criterion Element
The equation is:
$3I_{G0} > [64SInj.3I0\_Set] ………(5)$

Where:

- *$3I_{G0}$ is the zero-sequence current on the generator terminal;*
- *[64SInj.3I0_Set] is the residual current tripping setting.*
- *Zero-sequence current criterion element can detect single-phase ground fault of 80%-90% of stator winding of generator terminal, moreover the sensitivity is more high if the grounding point is more close to generator terminal.*

3.4. Injected Circuit Abnormality Alarm

Voltage measurement circuit and current measurement circuit abnormality will lead to the calculation error of ground transition resistance, so grounding resistance criterion element should be blocked but zero-sequence current criterion element will not be affected. The criteria to judge circuit abnormality is:

$U_{20} < U\_Superv$ *or* $I_{20} < I\_Superv$ *……(6)*

Where:

- *U_{20} is the low-frequency voltage;*
- *I_{20} is the low-frequency current;*
- *U_Superv and I_Superv are voltage circuit supervision setting and current circuit supervision setting respectively.*

If above condition is met, resistance criterion element of stator ground fault protection with 20Hz voltage injection will be blocked, and a circuit abnormally alarm signal will be issued with a time delay. It is recommended that U_Superv takes half of the possible minimum low-frequency voltage U20 during a most severe ground fault, and I_Superv takes half of the possible minimum low-frequency current I20 during normal operation , the value of U_Superv should be adjusted according to the actual operation condition.

3.5. Logic

- *For generator stator ground fault protection (with 20Hz voltage injection), if following three condition are met, the protection will be enabled.*
  - *Logic setting [64SInj.En] is set as "1" (on).*
  - *Protection function enabling inputs [64SInj.En1], [64SInj.En2] are "1" (on).*
  - *Protection function blocking input [64SInj.Blk] is "0" (off).*

- *If generator stator ground fault protection (with 20Hz voltage injection) is disabled, all the related output signal will be reset. If no external input is configured to [64SInj.En1] ([64SInj. En2]), the default initial value of [64SInj.En1] ([64SInj.En2]) is "1"; if no external input is configured to [64SInj.Blk], the default initial value of [64SInj.Blk] is "0".*

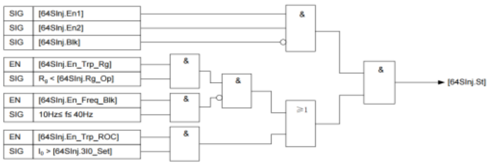

Fig 5. Logic diagram for Generator Stator Ground Fault Protection with 20 Hz Voltage Injection

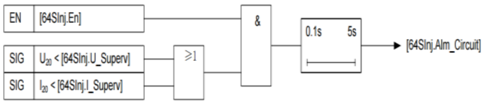

Fig 6. Logic diagram for Injected Circuit Abnormality Alarm

Where:

- *[64SInj.En1] is protection function enabling input 1, it can be binary input or setting, such as function enabling binary input, logic link, etc.*
- *[64SInj.En2] is protection function enabling input 2, it can be binary input or setting, such as function enabling binary input, logic link, etc.*
- *[64SInj.Blk] is protection function blocking input, such as function blocking binary input.*
- *[64SInj.En_Trp_Rg] is logic setting of enabling/disabling tripping stage of resistance criterion element of generator stator ground fault protection (with 20Hz voltage injection).*
- *R_g < [64SInj.Rg_Op] is the generator insulation resistance value under the resistance setting value.*
- *[64SInj.En_Freq_Blk] is logic setting of enabling/disabling frequency blocking function.*
- *10Hz ≤ f ≤ 40Hz is the actual frequency value in generator that can make protection blocking when generator not yet reach its rated frequency (50Hz).*
- *[64SInj.En_Trp_ROC] is logic setting of enabling/disabling tripping zero-sequence current criterion element of generator stator ground fault protection (with 20Hz voltage injection).*
- *$3I_{G0}$ > [64SInj.3I0_Set] is the zero-sequence current on generator terminal above the zero-sequence current setting value.*
- *[64SInj.En] is is logic setting of enabling/disabling generator stator ground fault protection (with 20Hz voltage injection).*
- *U_{20} < U_Superv is low-frequency voltage below voltage circuit supervision setting.*
- *I_{20} < I_Superv is low-frequency current below current circuit supervision setting.*

4. CONCLUSION

- *Traditional stator ground fault protection schemes like third harmonic voltage ratio schemes. These exhibit sensitivity, security and clearing speed issues that can make a generator to prolonged low level ground faults that may evolve into damaging faults.*

- *To mitigate the sensitivity, security and speed issues of traditional stator ground fault protection schemes, Stator Ground Fault Protection with 20 Hz Voltage Injection may be used. Stator Ground Fault Protection with 20 Hz Voltage Injection is used to identify ground faults regardless of operational mode or power level that cause difficulties with other schemes. But it can be adjust some logic to deal with it like in the discussion part there's some block signal if the frequency not yet reach rated frequency. Other disadvantages of Stator Ground Fault Protection with 20 Hz Voltage Injection is voltage injection device must be reliable. This paper clearly suggest third harmonic voltage ratio protection and Stator Ground Fault Protection with 20 Hz Voltage Injection install redundantly to back up each other with different method. Because some time traditional method is more durable but lack in other issues, combining traditional one with the advanced one, it will improve* *generator stator grounding protection reliability.*

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