A Novel Generator Protection Scheme Utilising Fault Transients

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Abstract - **This paper presents a new principle for protection of the stator of a generator. The technique utilises a specially designed multi-channel transient detection unit to detect the fault generated transient current signals. A spectral comparison technique is then applied to extract the spectral energies of signals detected and the internal and external faults are then discriminated by comparing the levels of the different band of energies. The scheme offers advantages of total immunity to CT saturation, and is capable of detecting low level and interturn faults.**

Keywords: Generator Protection, Fault Transient, Transient Based Protection

I. INTRODUCTION

One of the major and vital components in a power system is the synchronous generator. Any fault in the very source of power, i.e. synchronous generators may hamper the available power to a system. Hence, the problem of protecting this vital unit against all abnormal conditions and at the same time keeping protection schemes simple, reliable and fast in operation, has always posed a challenge to the power system engineer. The stator winding protection is central to the generator protection. Stator faults arise mainly through breakdown of conductor insulation due to overvoltage or overheating. A common cause of damage to insulation is conductor movement.

The stator fault includes phase to ground i.e. conductor to core faults, phase to phase faults and interturn faults. Severe arcing to the machine core burns the iron at the point of fault and welds laminations together. Replacement of the faulted conductor may not be a very serious matter but the damage to the core cannot be ignored. Welding of laminations is likely to result in local overheating. The fused metal can sometimes be cut away and replaced, but if severe damage has occurred, it may be necessary to rebuild the core, which would involve extensive dismantling of the winding. In practice the degree of fault current limitation varies from approximately rated current on the one hand to comparatively low values on the other.

The most widely method of protecting stator winding is the current differential technique. In the technique, the current transformers used at the two ends (high side and neutral) of a generator winding are specially matched so as to reduce the disparity in their performance. This is possible in the case of generators because the primary currents of the two CT's are identical. However, there are still a number of aspects where problems could arise[1]: (i) a ground fault close to the generator neutral would not be detected if the fault current were less than the sensitivity of relay differential setting. (ii) saturation of current transformers is possible, and would cause the protection to not operate or slow relay response times for internal faults. (iii) interturn faults, although uncommon, are not covered by the differential protection scheme and have commonly been disregarded on the basis that if they occur they will quickly develop into earth faults. This is probably true if the fault is in the slot portion but will take a little longer in the region of the end connection. An approach of this kind is never attractive and may be entirely unjustified; there is a possibility of the machine being very seriously damaged before the fault evolves to a condition that can be detected by the differential protection scheme. The interturn fault detection method currently available requires the use of additional voltage transformer, and a complex relay setting.

To solve the above mentioned problems, this paper presents a novel protection scheme for protection of the stator of a generator unit which is directly connected to the distribution system. In the scheme, a specially designed multi-channel fault transient detection unit, connected to the CTs at the output of the generator terminal, is employed to extract the fault generated transient current signals. The detector unit is tuned to extract two bands of fault generated transient signals with different centre frequencies. The spectral comparison technique is applied to firstly compute the spectral energies of the two band signals, the internal and external faults are then discriminated by comparing the ratio of the two signals with a predefined threshold. The scheme offers advantages of total immunity to CT saturation, and is capable of detecting low level and interturn faults. In addition, the scheme is also simple in application, and economical in cost since it only requiring one set of CTs. Simulation studies show that the proposed technique can give correct responses for various fault conditions.

II. BASIC RELAYING PRINCIPLE AND FAULT TRANSIENT DETECTION

A fault inside a power apparatus produces wideband signal. Much of this signal is outside the bandwidth used by present generation of protection. Research[2] on the characteristics of the fault generated high frequency transient signals found that the special features of the signal can be used not only to discriminated the internal fault from external fault, but also to detect low level faults which is not readily detectable by the present generator protection schemes based on the measurement of power frequency signals.

A. Basic Principle

Fig.1 shows a typical generator connected to a distribution line. The fault transient responses of the circuit are firstly examined in frequency domain. When a fault occurs on any of the points F1, F2, F3 or F4, a wide band transient current signal is generated, the magnitude of which decreases with the increasing in frequency. The signal path of the current is divided into two parts; the first part flows through the generator winding towards earth and the second flows towards the other end of the line. The magnitudes of the two signals vary with respect to frequency. For example, at lower frequencies, the impedance of the winding, which is inductive in nature, is relative low. At higher frequencies, the winding impedance is significantly increased when compared to that of line. Also the capacitance and capacitive coupling in the winding becomes more important. As a result, the fault generated transient current measured by the CTs will vary with the frequency and fault position in the system.

Fig.2 shows the magnitudes of fault transient current measured by the CTs vs. frequency for fault positions F1-F4. As shown in the figure, for fault inside the protected zone, the magnitudes of the fault generated high frequency transient signals remain constant from 1 to about 10 kHz (curve 1 and curve 2), on the contrary, for fault outside the protected zone (curve 3 and curve 4), the magnitudes of the transient current signals decrease significantly with the increase of frequency. This can be attributed to the factor that for an internal fault, most current signal of at lower frequency will be shunt to earth by the low impedance of the winding, however at higher frequency, with the increasing in impedance, the percentage of the current flow into earth will be less in comparison. This valuable characteristic can be used to distinguish between internal and external faults.

B. Detection of Fault Generated Transients

As shown in the Fig.1. the proposed relay unit is connected to the CTs at the output of the generator terminal, and is designed to extract the fault generated transient current signals. The signals captured from the CTs are first combined to form a composite signal[3] by which the background noise is effectively removed. For the simplicity of explanation, only one mode signal is used in the studies.

The detector unit is tuned to extract two bands of fault generated transient signals with two different centre frequencies 5 kHz and 1 kHz respectively by filter 1 and filter 2. The spectral energies of the output of the filters, I_1 and I_2, are then extracted by the moving average computational process[3] to produce the operate and restraint signals.

$$I_{op}(n\Delta T) = \sum_{k=n-M}^{n} I^2{}_1(k\Delta T)k'\Delta T$$
$$I_{op}(n\Delta T) = \sum_{k=n-M}^{n} I^2{}_2(k\Delta T)k'\Delta T \qquad (1)$$

where ΔT=time step length; k'=attenuation factor; M=no. of samples in the window.

The equation(1) processes a window of the moving waveform of 2 ms (i.e. M=50 at a sampling frequency of 25 kHz).

The internal and external faults are then discriminated by comparing the ratio of the two signals with a predefined threshold:

$$\text{Ratio} = k\, I_{op} / I_{re} \qquad (2)$$

In the studies here, the value of k is chosen as 400.

III. SIMULATION STUDIES

A. Simulation of Generator Internal Faults

The EMTP software package was used in the simulation studies. The method adopted for modelling generator internal fault is essentially based on those works of Sidhu, Sachdev and Sunga[4]. At the frequencies used in the studies, over 1 kHz, capacitance and capacitive coupling among windings become important, therefore, the shunt capacitances were included in the model. The simulation considered is a typical 22 kV generator directly connected to a distribution line as shown in Fig.1.

B. Typical Internal and External Fault Responses

Fig.3 shows the relay responses attained for a phase to earth fault at the mid-point of phase 'a' stator winding inside the generator, F1 as shown in Fig.1. Fig.3a(i) shows the current at the end of the generator. As expected, the faulted phase 'a' exhibits a high degree of distortion. Fig.3a(ii) shows the corresponding signals of filter 1 and filter 2 outputs. Their spectral energies are given in Fig.3b(i). Since this is a internal fault, the level of the operate signal is relatively low in comparison with that of restraint, as a result, the discrimination ratio of the two signals is higher than the presetted threshold as shown in Fig.3b(ii).

Fig.4 shows the responses to an 'a'-earth external fault on the line immediately outside the CT at F3 as shown in Fig.1. In this case, as shown in Fig.4a(i) the faulted phase current is significantly high comparing to that in case of internal faults. The detector outputs of both channels as shown in Fig.4a(ii) are such that the magnitude of the operate signal derived is significantly smaller than that of restraint signal as shown in Fig.4b(i) and as expected the level of the spectral energy of the operate signal is much lower than that of restraint signal. As a result, the relay is inhibited from tripping for this external fault condition as shown in Fig.4b(ii).

C. Responses to Low Level Faults

Fig.5 shows the relay response to a 5% turn-turn fault at phase 'a' winding 10% from the neutral point. It can be seen from the CT outputs shown in Fig.5(i), there are no noticeable evidence to indicate the occurrence of a fault, in particular, there is little change at the CT output. These fault will therefore probably not be detected by the conventional relay based on the measurement of power frequency components. However, it is clearly evident from the detector outputs as shown in Fig.5(ii) that the fault is clearly recorded by the transient detector, and the spectral energies of the operate and restraint signals clearly indicate that this is an internal fault as shown in Fig.5(iii).

Fig.6 shows the responses to an 'a'-earth external fault at mid of the line, F4 as shown in Fig.1. The fault inception angle is zero degree. Although this low level fault does not generate much travelling wave signal as shown in Fig.6(i), the relay responses clearly indicate that this is an external fault and the relay remains stable as shown in Fig.6(iii).

IV. CONCLUSIONS

A new technique for generator protection has been presented in the paper. The technique is based on the detection of fault generated high frequency current

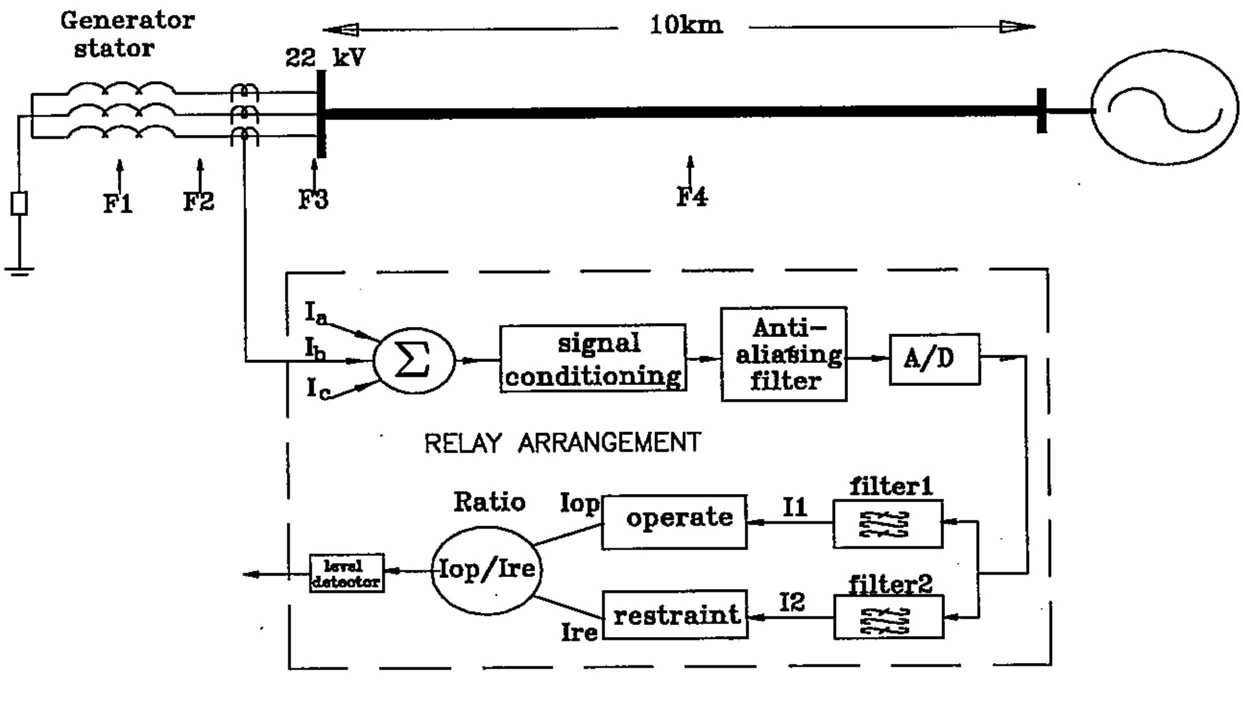

Fig.1 Simulated system with relay unit

transients. The results of simulation studies revealed that the proposed technique is not only able to give very fast and correct responses to under different fault conditions, but also able to detect generator internal low level and inter-turn faults.

V. REFERENCE

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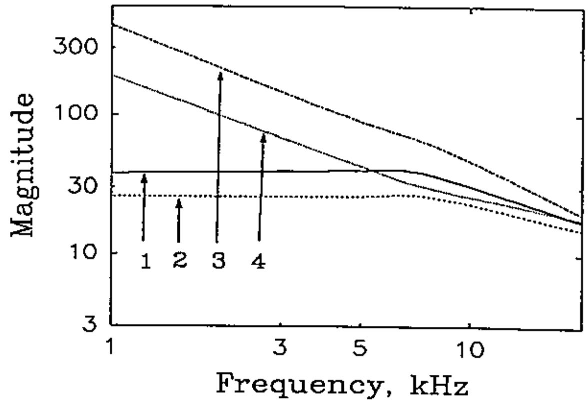
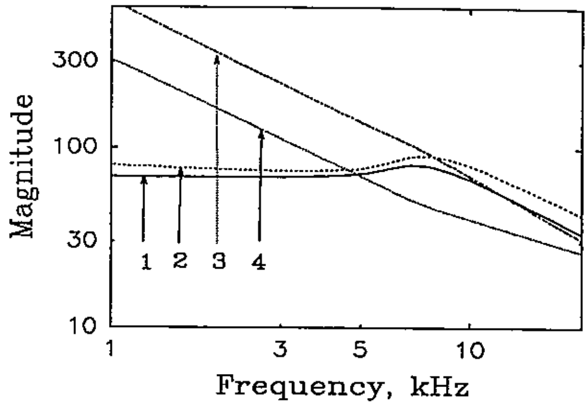
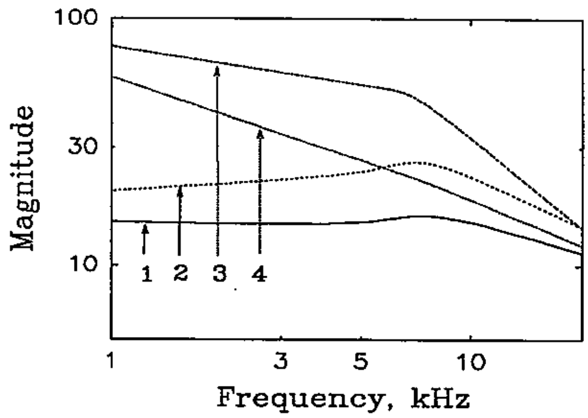


(a) earth fault

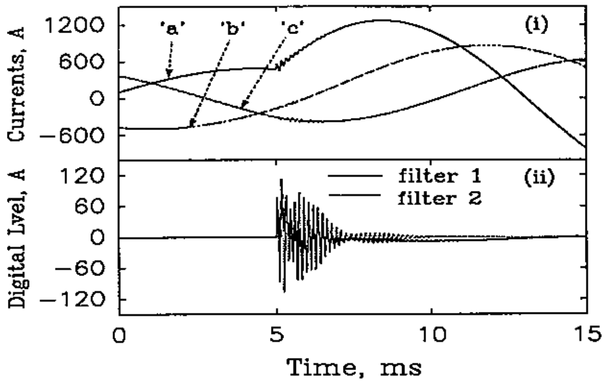


(b) phase-phase fault

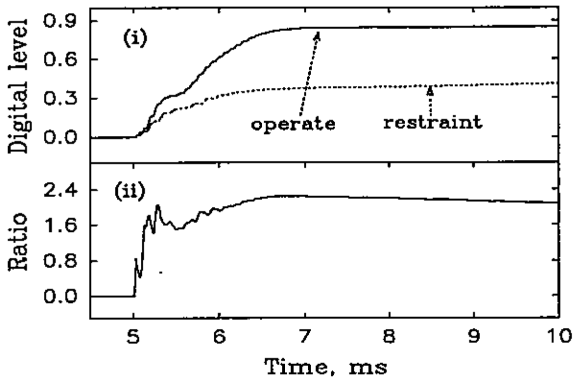


(c) high impedance earth fault

Fig.2 Signal magnitude vs frequency of transient signals 1-fault inside generator; 2-fault on the generator side of CTs; 3-fault on the line side of CTs; 4-fault on the mid of the line

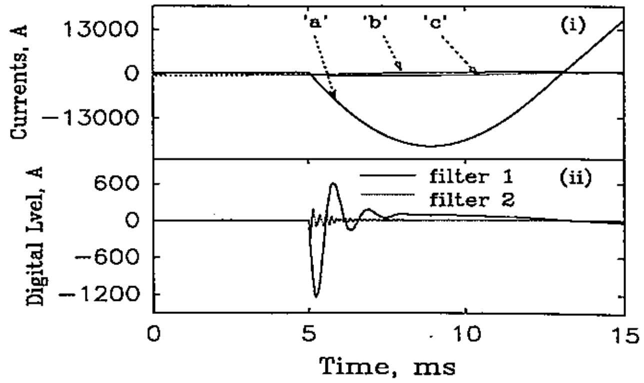


3a (i) CT outputs; (ii) filter 1 and filter 2 outputs

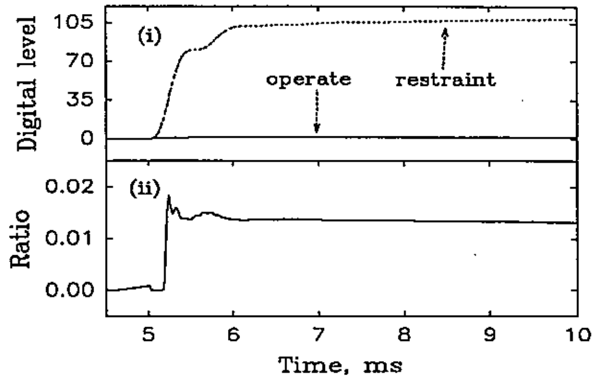


3b (i) operate signal and restraint signal; (ii) discrimination ratio

Fig.3 Responses for a turn to earth fault at the mid-point of phase 'a' inside generator, fault inception Tf=5ms

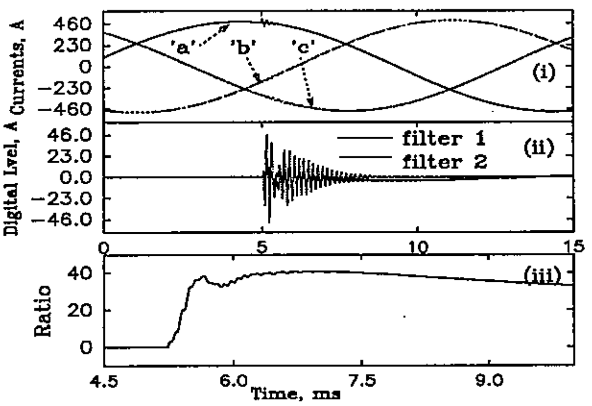


4a (i) CT outputs; (ii) filter 1 and filter 2 outputs



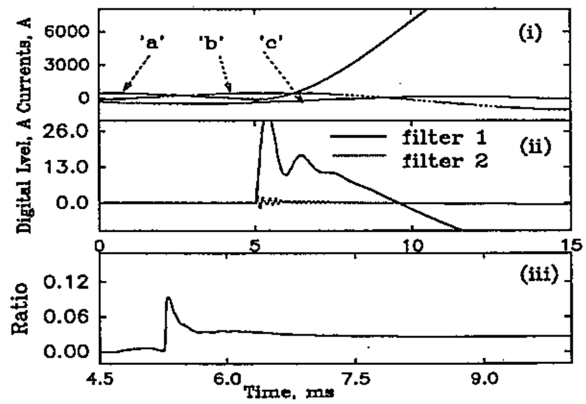
4b (i) operate signal and restraint signal; (ii) discrimination ratio

Fig.4 Responses for a turn to earth fault on phase 'a' on the line side of the CTs, fault inception Tf=5ms



(i) CT outputs; (ii) filter 1 and filter 2 outputs; (iii) discrimination ratio

Fig.5 Responses for a 5% turn-to-turn fault on 'a' phase at the at 10% of winding from the neutral point, fault inception Tf=5ms



(i) CT outputs; (ii) filter 1 and filter 2 outputs; (iii) discrimination ratio

Fig.6 Responses for an 'a' phase to earth fault at mid of line, fault inception angle=0°, fault inception Tf=5ms