A New Novel of transverse differential protection Scheme

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***Abstract* – As one of generator main protections, transverse differential protection is the most simple but sensitivity one. It is widely used in huge generators'. With system development, it meets with much more challenges. To meet with the practice requirement, this paper gives out a new novel of transverse differential protection scheme. It chooses two elements to fulfill the sensitivity and the credibility respectively. The main criterion is the transverse differential element which decides whether the protection acts or not. The negative sequence direction element is the assistant criterion. It just only distinguishes whether faults in internal or external ones. When it judges there is external fault, it may increase the threshold much higher to avoid the mis-operation. The sensitivity of the new scheme is determined by that of the transverse differential element, while the credibility is dependent on the negative sequence direction element. The experiment test shows that this new scheme is doable and has prefect performance in both internal and external faults.**

Keywords – transverse differential protection, directional negative sequence power element, imbalance current, operating threshold

I. Introduction

With system development, the capacitance of a single generator becomes huger and huger. The possibility and damage of internal faults are greater and greater. So it brings forward much more rigorous commands on relay protections about the reliability, sensitivity, selectivity and celerity.

Experiment investigations and filed applications show that the transverse differential protection installed in the neutral connection has many advantages such as simplified martingale、complete serviceability (means can protect all kinds of internal faults), thus it is usually used as the main protection of large or huge hydro-generator.[1][4][5]

In internal faults, the transverse differential current varies with the load current and the proportion of short turns. With the number of short turns decreasing, the minimal transverse differential current is lower and lower in internal faults. For example, for the one turn interturn fault of the generator in the Three Gorges Project, the transverse differential current is much slower than 100 ampere while the phase rate current is 22453 ampere. [4][5] But in practice to avoid mis-operation, the transverse differential protection for generator must rise up its operation threshold over the maximal imbalance current of all sorts of loads and external faults.

To increase the sensitivity the transverse differential protection in internal faults especially in interturn faults, the protection threshold should be reduced as low as possible. But there still exists a challenge that the transverse differential current of the lightest internal fault is lower than that of the maximal imbalance one (showed in fig3). Now the transverse differential protection scheme does not meet with the sensitivity command of large generators'.

This paper put forward a new scheme which chooses two elements to fulfill the sensitivity and the credibility respectively. The main criterion is the transverse differential element which decides whether the protection acts or not. The negative sequence direction element is the assistant criterion. It just only distinguishes whether faults in internal or external ones. When it judges there is external fault, it may increase the threshold much higher to avoid the mis-operation. In the way the threshold of the transverse differential protection can be decreased as much as possible in internal faults. The sensitivity of the new scheme is determined by that of the transverse differential element, while the credibility is dependent on the negative sequence direction element. The experiment test shows that this new scheme is doable and has prefect performance in both internal and external faults.

II. Analyzing the Feature of the Current in the Salient Pole Generator's Neutral Connection

It is ideally that there is no current in the generator neutral connection in all sorts of loads, external faults or oscillation. However, it is reasonable that the generator and system are asymmetry in practice. There exists a lesser transverse differential current changing a little along with the load. When an external fault takes place, the transverse differential current is augmenting. That is what usually called as the imbalance transverse differential current. Thus to avoiding mis-operation in external faults, the setting value must be greater than the maximal imbalance current.

In internal faults the transverse differential current varies with the load current before the fault and the number of short turns. For the lightest potential internal fault the transverse differential current is very small. For example, for the one turn interturn fault of the generator in the Three Gorges Project, the transverse differential current is much slower than 100 ampere while the phase rate current is 22453 ampere. Although there is very little possibility of such venial faults, it also need operate accurately all the same. In such cases transverse differential current may smaller than the maximum of imbalance one.

To clearly illuminate the characteristic of the transverse differential current in internal faults and external ones, experiments have been done in dynamic modeling laboratory of HUST, and results are also given in the below.

A. Experimental Connection

The rating capacity of experiment generator is 15kVA; the rating voltage is 200V; the rating current is 43.3A. The idiographic connection and the inter connection of dynamic modeling generator is given in fig1 and fig2 separately.

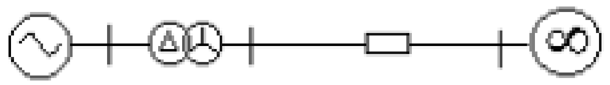

Fig. 1 The idiographic connection of experiment modeling

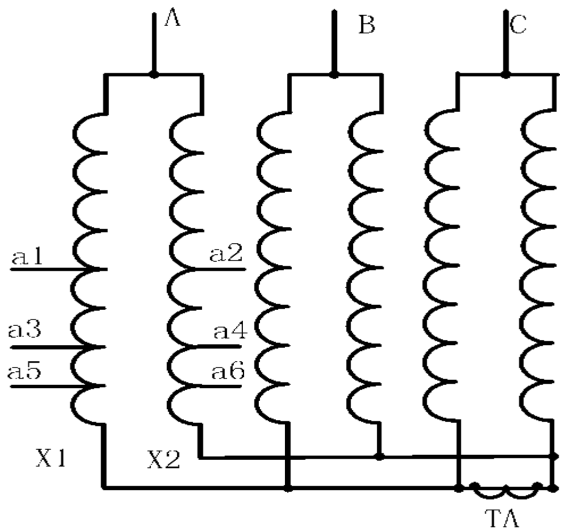

Fig.2 The sketch map of inter connection about the dynamic modeling generator

In fig2 the derivation of interturn fault is at the symmetry place in the generator two branches of phase A. Supposing the whole voltage of phase A is 110V, the possible short point can express as the voltage proportion as table1.

Derivation point	Voltage to neutral point	Voltage proportion
a1(a2)	51V	46.36%
a3(a4)	21V	19.09%
a5(a6)	7V	6.36%

Tab1 The voltages and proportions of .the short points

B. The transverse differential current at small number of turns interior fault comparing with that at external fault

In interior fault, the transverse differential current is related with the fault position and the number of short turns. There are only six points of phase A that can make short fault experiment in the dynamic modeling generator. Those six points are a1、a2、a3、a4、a5 and a6. From above, the least conceivable short proportion is 6.36%, which is short of a5 to x1 or a6 to x2.

The short current of the transverse differential relay are shown in fig3. To comparison, the most external serious fault, the terminal three phases fault, is also present. To understand easily, the values are all changed to CT secondary relatively ones. The below are all alike.

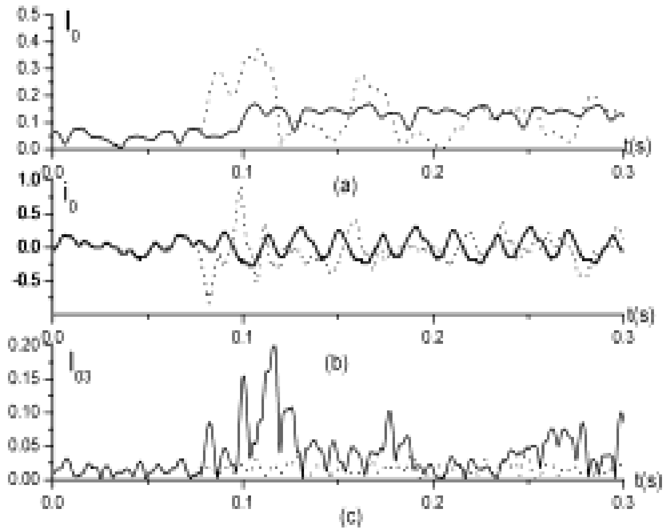

Fig.3 The transverse differential current at small number of turns internal fault and at external fault

(a) The fundamental virtual value (b) The instantaneous value (c) The third harmonic virtual value

——current wave of interturn short about a5 to x1

----- current wave of three phase external fault

From fig3, in lab experiment condition the transverse differential current is very tiny in the internal light fault. Its current instantaneous value is smaller than that of external fault. But in interior fault the main component of the transverse differential current is fundamental component, and its third harmonic is very small. While in external fault the third harmonic component is much greater, and can be compared with fundamental one.

Those have some physics reasons:

1) The terminal three phase currents have no distinct changes at light interior faults. In this case the main component of the stator current is positive fundamental sequence component, which produces fundamental current in the neutral connection.

2) The transient currents of generator three phases are no longer symmetry in external fault even three phase short fault in transient. There exists negative sequence component in phase current at the short transient process. It induces second harmonic at rotor, which rotate at synchronous rate and produces third harmonic current in stator neutral connection. On the other hand, the generator rated load is at the saturation segment of iron magnetism force. The phase fault current has attenuate direct current causing saturation change. Such causes third harmonic current in stator

neutral connection even the phase currents are almost symmetry.

In fact whether in external faults or interior faults, the generator three phases current has not only positive sequence component but also negative sequence component, which makes the neutral current has both fundamental and third harmonic component.

III.THE TRANSVERSE DIFFERENTIAL PROTECTION BASED ON DIRECTIONAL NEGATIVE SEQUENCE POWER ELEMENT

The traditional transverse differential scheme applies the transverse differential element to achieve both the sensitivity of internal faults and the credibility of external faults. To avoiding mis-operation in all external faults, the transverse differential protection may not be sensitive to some internal faults. The protection research staffs are working hard to find some new methods to solve this problem. [1][3]

For the external fault current consist much third harmonic component, the high-powered filter put forward before the current used by the transverse differential relay.[1] But that method is not the suitable one if the fundamental component of imbalance current is bigger than the lighter internal fault one.

Since in the external fault, the third harmonic component is very big, someone suggest introduce it into the transverse differential protection as the restraint element. If the proportion between the third harmonic and the fundamental is greater than the setting, the fault is considered as external one, and the protection is locked. But the proportion is interrelated with the structure and electromagnetic condition. Different generator may have different proportion. So in practice giving a suitable setting is very difficult. [2]

From the dynamic modeling experiment data, it shows that to improve the sensitivity to the internal fault, the transverse differential relay must reduce its operating threshold. The most important factor to make it reality is to distinguish the fault occurs at internal or external. In filed the directional negative sequence power relay has been well used as the main protection of large generator for years. Therefore the paper put forward a new transverse differential protection that uses directional negative sequence power component to distinguish the fault position. When it judges the fault is external one, it would raise up the operation threshold, thus closedown the transverse differential protection. In the way, the threshold can reduce greatly in internal faults.

Below, the author discusses the constitution of the directional negative sequence power component and its cooperation with the transverse differential protection.

A. The directional negative sequence power element

When there occurs a asymmetry fault, it could be regard as appending an additive fault component source, which cause fault negative sequence voltage $\Delta\dot{U}_2$ and fault negative sequence current $\Delta\dot{I}_2$. For the internal fault, the fault power ΔP_2's directions are all flow from internal to external in measure point. For the external fault, they are the other way round. This is the theoretical foundation. Using the fault component theory can avoid the imbalance of system asymmetry at normal.

But when there occurs internal fault before generator is incorporate in power network, the stator current is zero (in fact, there exists the transformer excitation current, yet very small.), because the generator breaker is not closed. So internal faults (short or opening fault) are both have only $\Delta\dot{U}_2$, and $\Delta\dot{I}_2=0$. Thus ΔP_2 equal to zero constantly, the protection reject operation. This is the inherence shortcoming of the directional negative sequence power element. That is say it loses its function during the generator startup. Therefore it would use with other element, and in order to protect the startup it must add $(|\Delta\dot{U}_2| \rangle \varepsilon_{U2}) \cap (|\Delta\dot{I}_2|=0)$ as the second criterion.

The fault negative sequence power component ΔP_2 is calculated as the below formula:

$$\Delta P_2 = 3R_e[\Delta\dot{U}_2 \, \Delta\overset{*}{I}_2 \, e^{-j\phi_2}] \quad (1)$$

There: $\Delta\dot{U}_2$ is the terminal fault negative sequence voltage component, $\Delta\overset{*}{I}_2$ is the conjugate vector of the terminal fault negative sequence current component, ϕ_2 is the sensitive angle of the negative direction, usually 70～80°.

The negative sequence direction element must operate correctly whether generator corporate or step out power network, so the action criterion is made up of:

① Criterion one: generator is incorporate in power network

$$\Delta P_2 \ \rangle \ \varepsilon_{P2} \ \rangle \ 0 \quad (2)$$

There: ε_{P2} denotes the threshold of the negative sequence direction component.

② Criterion two: generator step out power network

$$(|\Delta\dot{U}_2| \rangle \varepsilon_{U2}) \cap (|\Delta\dot{I}_2|=0) \quad (3)$$

B. The cooperation of the directional negative sequence power element and the transverse differential element

The new protection scheme consists of two elements. The transverse differential element is the main criterion. It decides whether the protection operates or not. The sensitivity of the new scheme is determined by the sensitivity of the transverse differential element. The negative sequence direction element is the assistant criterion. It is just only distinguish faults in internal or external ones. The credibility is dependent on the negative sequence direction element.

When system occurs the external asymmetry faults、imbalance load、removal of external asymmetry faults, the directions of ΔP_2 are all reverse and $\Delta P_2 \ \langle \ \varepsilon_{P2}$. Although the imbalance current is augmenting with fault status, more serious of external faults more reliable of the judgment. So the setting of ε_{P2} only need considering of the ΔP_2 imbalance at generator normal operation and is usually much lower. In internal faults it is easily to meet with $\Delta P_2 \rangle \varepsilon_{P2}$. That is to say in internal faults the sensitivity of the negative sequence direction element is higher than that of the transverse differential element.

The main purpose of adding the directional negative sequence element distinguish that the fault place is internal or external generator. It just conceives that the imbalance transverse current is not big which is produced by the external light faults. So the most important thing is to distinguish the external much serious faults. Thus the negative direction element should not make as sensitive as it used as the main internal fault protection. Its threshold could set a little higher to improve its performance in instantaneous.

The transverse differential current is much great in serious internal fault. So it adds a rapid segment for the sake of picking up the protection speed. This segment can set as several times of the maximal external fault imbalance current.

From above analyzing, unlike the traditional transverse differential scheme, the novel scheme chooses two elements to fulfill the sensitivity and the credibility respectively. Thus it can have prefect performance in both internal and external faults.

The flow of such transverse differential protection based on negative direction element is showed as fig4.

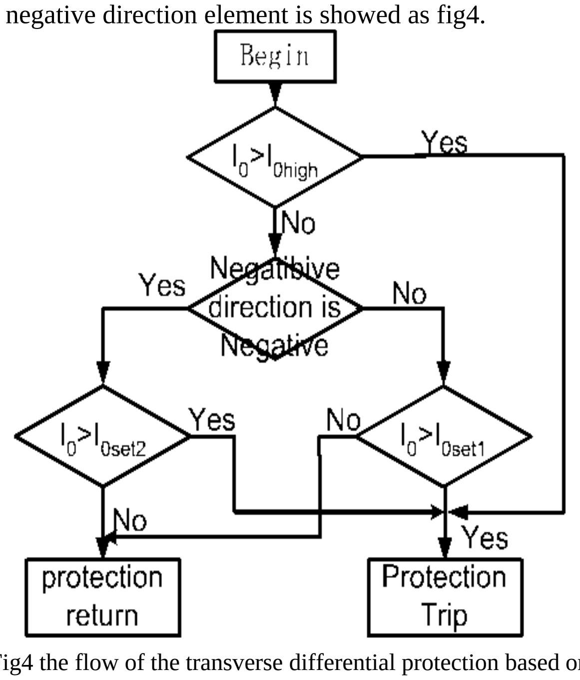

Fig4 the flow of the transverse differential protection based on negative direction element

The setting I_{0high} is the setting to quickly operate in serious cases. The setting I_{0set1} and I_{0set2} are the low and high setting separately. If the negative directional element distinguish that the fault is external one, the transverse differential protection uses the high setting to avoid mis-operation. This high setting can be designed as the traditional one that does not add the assistant criterion. Otherwise it applies a much lower setting to improve its sensitivity. The low setting only needs to consider the maximal imbalance current in normal condition. Thus by the application of the assistant criterion, the transverse differential protection can achieve the sensitivity in inter faults and the reliability in external ones at the same time.

C. The experiment test

To test the validity of the scheme, we do many experiments in the lab. The experimental situation is the same as fig1 and fig2.

In order to get the threshold of the new scheme, the transverse differential current in normal must be obtain at first. Ideality the generator has no current in the neutral connection when its three phase load is symmetry or it occurs external fault. But in fact, there exists imbalance current for the practical factors such as design、manufacture、installation and the circumstance in practice.[3]

Normally the imbalance current in the transverse differential relay is small and given by fig5. It shows that the transverse differential current varies minutely with the generator load: more load, more imbalance current.

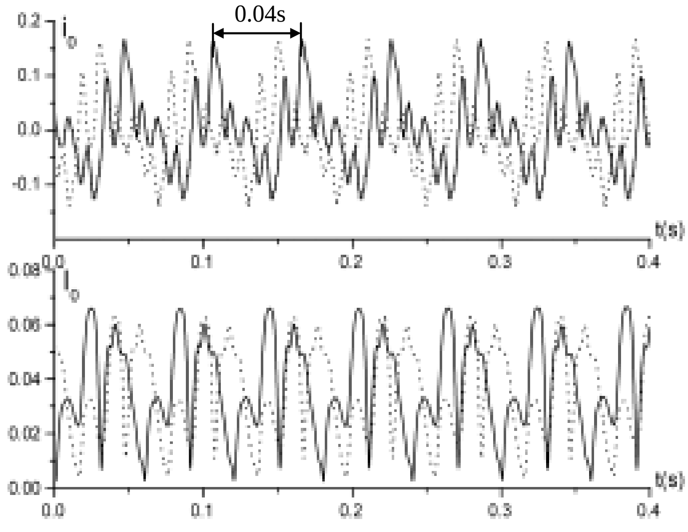

Fig5 the imbalance current of the generator transverse differential relay
------ zero load —— full load

From fig5, in that case the main component of the imbalance current is the 25HZ low frequently current. Because in practice the generator stator and rotor gas gap could not be made absolutely symmetry, so the gap arises asymmetry change while the generator goes around. When the rotor has rotated a circle (360 ° geometrical angle), the gap width make a periodicity changes. The dynamic modeling generator has two antipode poles (p=2), so the time that the rotor rotates a circle needs 0.04 second.

From the experiment, the maximal imbalance current of normal is 0.06 I_e (the rating current). It is much lower than that of the maximal imbalance current, which is more than 0.20 I_e shown in fig3.

For the new scheme, the setting can only consider the normal maximal imbalance current. So let the transverse differential protection threshold be 0.09 I_e, and the fault negative sequence power component ΔP_2 be 0.05 P_e (the rating power).

The experiment result shows that in external faults the negative direction element locks the transverse differential protection reliably, while in light internal faults it has no effect, the transverse differential protection can act acutely.

IV. Conclusions

The setting of the traditional transverse differential protection is decided by the maximal imbalance current, which is gained by the maximal experiment imbalance current linearity extrapolating to the three phase terminal short fault. So the fixed value is much high. Its sensitivity to most of interturn fault is inadequate.

In this paper, author presents a novel transverse differential scheme. It chooses two elements to fulfill the sensitivity and the credibility respectively. The main criterion is the transverse differential element which decides whether the protection acts or not. The negative sequence direction element is the assistant criterion. It just only distinguishes whether faults in internal or external ones. When it judges there is external fault, it may increase the threshold much higher to avoid the mis-operation. The sensitivity of the new scheme is determined by that of the transverse differential element, while the credibility is dependent on the negative sequence direction element.

So the setting can only consider the normal maximal imbalance current, thus the sensitivity of transverse differential protection can improve greatly. In external faults, the negative direction element locks the transverse differential protection reliably, while in light internal faults it has no effect, the transverse differential protection can act acutely. The experiment test shows that this new scheme is doable and has prefect performance in both internal and external faults.

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I. BIOGRAPHIES

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