微机人工二次谐波发电机定子单相接地保护

颜卓胜　李振然　广西大学电气工程系 (530004)

【摘要】 本文提出在发电机中性点消弧线圈(或配电变压器)的二次线圈中加入人工二次谐波电流, 通过检测二次谐波电压与二次谐波电流间相位差, 与基波零序电压保护一起可构成 100% 定子单相接地保护。

【关键词】 发电机定子单相接地保护　二次谐波　富里叶变换

前言

许多专家学者对发电机定子单相接地保护进行了大量研究工作, 提出了许多方案, 到目前仍然存着一些问题, 有待进一步解决。由基波零序电压构成的发电机定子单相接地保护, 其原理和接线都比较简单, 但由于整定要避开正常运行时零序滤过器的不平衡电压, 发电机电压中的三次谐波以及变压器高压侧接地时由于变压器高低压线圈之间有电容存在而在发电机机端出现的零序电压, 所以整定值比较大, 保护有 15% 到 30% 的死区, 采取措施后仍有 5% 到 10% 的死区。为了消除死区, 一般采用基波零序电压保护加反应发电机中性点和发电机机端的三次谐波电压的比值或者外加电源方式。外加电源方式有: 外加直流电源的定子接地保护, 外加 20Hz 交流电源的定子接地保护和外加 100Hz 交流电源的定子接地保护等。

由基波零序电压和三次谐波电压构成的 100% 定子接地保护是目前应用得最多的一种保护方式。运行情况表明, 基波零序电压保护动作情况比较正常, 而三次谐波电压保护误动作现象比较普遍, 原因是发电机中性点三次谐波电压 U_{N3} 和发电机机端的三次谐波电压 U_{s3} 随机组的运行工况变化较大, 与理论上 U_{N3}/U_{s3} 比值随机组的运行工况的变化而变化较小不相符合。采用中性点迭加直流电源的定子接地保护的运行情况也不理想。

目前已有的外加 100Hz 交流电源的定子接地保护是将单相工频电压经半波整流后加到发电机中性点消弧线圈的二次线圈上, 在正常运行时就有外加电源产生的零序电流 I_0 流经消弧线圈一次侧, 它含有基波和所有偶次谐波, 偶次谐波中以二次谐波为最大, 经发电机中性点电流互感器取出得电压 U_i, 同时零序电流 I_0 在发电机定子回路中产生零序电压, 经发电机机端电压互感器的开口三角线圈通过 100Hz 带通滤波器后得到电压 U_u, 继电器反应 U_u/U_i 的大小, 正常运行时 $U_u/U_i > 1$, 继电器不动作, 发电机定子绕组发生单相接地时 $U_u/U_i < 1$, 继电器动作[1]。这种保护方式, 当定子绕组机端等效电容较大时, 其容抗较小, 加以 I_0 也比较小, 因此在正常运行时, U_u 比较小, 所以这种保护方式灵敏度比较低。

从进口机组采用中性点配电变压器二次电阻上迭加 20Hz 交流信号的定子单相接地保护运行情况较好, 但由于需要特殊的交流信号电源, 这是麻烦的问题, 而且当用在中性点经消弧线圈接地的发电机, 其灵敏度较低。

根据上述, 本文提出一种微机人工二次谐波型定子单相接地保护。

1　装置原理

1.1　装置原理

收稿日期: 1996—12—04

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.n

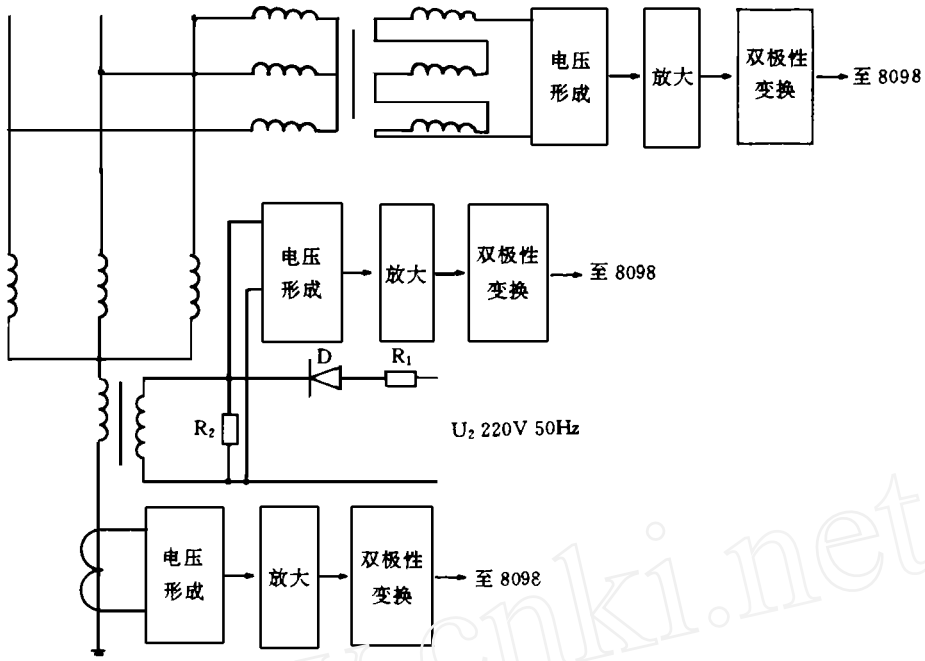


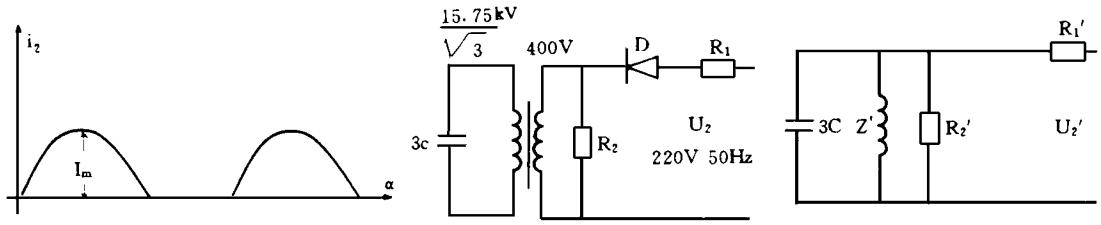
图 1

人工二次谐波型定子单相接地保护的原理框图如图 1 所示, 单相工频电压 220V 经半波整流后加到发电机中性点消弧线圈(或配电变压器) 的二次线圈(另外加装) 上。

单相工频电压经半波整流后, 回路中电流波形如图 2a 所示, 对半波电流用富里叶级数公式进行分解和简化后得:

$$i_2 = 0.318I_m + 0.5I_m \sin\omega t - 0.212I_m \sin 2\omega t - 0.0424I_m \cos 4\omega t \quad (1)$$

从上式可见半波整流后出现直流分量、基波分量、二次谐波分量和四次谐波分量等, 其中直流分量流入励磁支路, 其余交流分量都传变到消弧线圈一次侧。消弧线圈电路如图 2b 所示。其等值电路如图 2c 所示。



(a) (b) (c)

图 2

假设定子绕组对地电容加上发电机机端外接设备的对地电容得到发电机机端等效电容 $3C = 1\mu F$, 发电机相电压为 $15750/\sqrt{3}$ V, 消弧线圈一、二次线圈变比为 $n = \dfrac{15750}{\sqrt{3} \times 400} = 22.76$, 电阻 R_1 归算至一次侧为 $R_1' = n^2 R_1$ ($R_1 = 2\Omega$), 电阻 R_2 为 20Ω, 外加工频电压为 220V, 归算至一次侧为 $U_2' = nU_2$, 励磁支路阻抗 Z 和电阻 R_2 由于较大可略去。

正常运行时归算至一次侧的基波电流 I_1', 二次谐波电流 I_2' 和四次谐波电流 I_4' 的有效值分别为:

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.n

$$I_1' = 0.5\frac{U_2'}{X_{C1} + R_1}, \tag{2}$$

$$I_2' = 0.212\frac{U_2'}{X_{C2} + R_1}, \tag{3}$$

$$I_4' = 0.0424\frac{U_2'}{C_{C4} + R_1}, \tag{4}$$

式中 X_{C1}、X_{C2}、X_{C3} 分别为对应于基波、二次谐波、四次谐波电流时发电机机端等效电容的电抗。

消弧线圈二次线圈中的基波电流 I_1, 二次谐波电流 I_2, 和四次谐波电流 I_4 的有效值分别为:

$$I_1 = nI_1' \tag{5}$$

$$I_2 = nI_2' \tag{6}$$

$$I_4 = nI_4' \tag{7}$$

二次线圈中各谐波电流有效值的平方和根即为这些谐波电流之和的复波电流的有效值 I_P。

$$I_P = \sqrt{I_1^2 + I_2^2 + I_4^2}$$

二次线圈电流中直流分量 I_d 由下式求出:

$$I_1 = 0.5\frac{I_m}{\sqrt{2}}$$

所以　$I_m = \dfrac{\sqrt{2}I_1}{0.5}$

$$I_d = 0.318I_m = 0.318\frac{\sqrt{2}I_1}{0.5} \tag{8}$$

二次线圈总电流 I_Σ 为　$I_\Sigma = I_P + I_d$ (9)

二次线圈可按 U_2 和 I_Σ 来设计, 根据图 2 所给定参数得 $U_2 = 220V$, $I_\Sigma = 36.8A$

当经过渡电阻 R_m 接地时, 二次谐波电流(归算至一次侧) 按下式计算:

$$I_2' = \frac{0.212U_2'}{R_m /\!/ X_{C2} + R_1}, \tag{10}$$

表 1 为当 R_m 为不同值时, I_2' 和 U_2' 与 I_2' 之间相位差 φ 值。对动作区达 100% 的定子接地保护, 灵敏度是以保护区内任一点发生接地故障时, 保护装置刚能动作所允许诸最大过渡电阻中的最小值来表征。

表 1　当 $3C = 1\mu F$, $R_1 = 2\Omega$ 不同 R_m 时 I_2' 和 φ 值

	正常运行	$R_m = 0$	$R_m = 500\Omega$	$R_m = 1k\Omega$	$R_m = 10k\Omega$	$Rm = 5k\Omega$	$Rm = 20k\Omega$
I_2'	$0.559\angle\varphi + 57°$	$1.025\angle\varphi + 0°$	$0.709\angle\varphi + 5.5°$	$0.586\angle\varphi + 14.4°$	$0.527\angle\varphi + 50.0°$	$0.51\angle\varphi + 44°$	$0.541\angle\varphi + 53.7°$
φ	$-57°$	$0°$	$-5.5°$	$-14.4°$	$-50.0°$	$-44°$	$-53.7°$

从表 1 可见, 如果用二次谐波电流大小作为动作判据, 动作的灵敏度不会很高, 它允许过渡电阻不会超过 1000Ω。如果应用二次谐波电压与二次谐波电流的相位差 φ 即回路的阻抗角作为动作判据, 令动作相位差 φ_{dz}

$$\varphi_{dz} = 50° \tag{11}$$

当　$\varphi \leq \varphi_{dz}$

时保护动作, 则 $R_m = 10k\Omega$, 灵敏度比用二次谐波电流大小时为高。

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.n

为了减小定子单相接地时的电流, 二次线圈外加单相工频电压U_2选择为220V, 当在定子绕组某相(与二次线圈供电电压同相) 的中点至发电机机端发生单相接地时, 二次线圈输出电压将大于220V, 二极管D 处于反向电压而截止, 所以本装置不反应定子绕组某相的50% 至100% 处的单相接地。由于基波零序电压保护可保护定子绕组的30% 至100% 的单相接地, 所以本装置应与基波零序电压保护配合使用, 以实现对定子绕组100% 的单相接地保护。

为了测量出二次谐波电压与二次谐波电流之间的相位差, 可从图2 电阻R_2两端电压中, 通过放大电路和双极性变换器送至8098单片机, 经过单片机内的采样保持和A/D 转换后得到一系列采样值。利用富里叶变换, 可从二次谐波电压和二次谐波电流的采样值中分别求出二次谐波电压和二次谐波电流的实部和虚部, 利用它们可分别求出二次谐波电压的相位和二次谐波电流的相位以及二次谐波电压与二次谐波电流之间的相位差[2]。

为了提高测量精度, 必须采用自适应调整采样间隔技术[2]。

1.2 富里叶变换

对$i(t)$信号每周波采样N次($N = 12$), 产生采样序列$\{i_k\}$:

$$i_k = A\sin\left(\frac{2\pi}{N}k + \psi\right) \tag{12}$$

对i_k进行离散富里叶变换得二次谐波电流分量的频谱系数$i_2(k)$:

$$\begin{aligned} i_2(k) &= \frac{2}{N}\sum_{k=0}^{N-1} i_k e^{-j\frac{2\pi}{N}2k} \\ &= \frac{2}{N}\sum_{k=0}^{N-1} i_k \cos\frac{2\pi}{N}2k - j\frac{2}{N}\sum_{k=0}^{N-1} i_k \sin\frac{2\pi}{N}2k \\ &= i_{2I} - j\,i_{2R} \end{aligned} \tag{13}$$

i_{2I}、i_{2R}为二次谐波电流的虚部和实部, 将上式展开得:

$$i_{2I} = \frac{1}{6}\left[i_0 + i_6 - i_3 - i_9 + \frac{1}{2}(i_1 + i_5 + i_7 + i_{11} - i_2 - i_4 - i_8 - i_{10})\right] \tag{14}$$

$$i_{2R} = \frac{\sqrt{3}}{12}\left[i_1 + i_2 + i_7 + i_8 - i_4 - i_5 - i_{10} - i_{11}\right] \tag{15}$$

$$\varphi_I = \arctan\frac{i_{2I}}{I_{2R}} \tag{16}$$

式中φ_I为二次谐波电流相位, 由i_{2I}, i_{2R}通过查表可求得φ_I

同理可由下式求出二次谐波电压的虚部U_{2I}和实部U_{2R}以及二次谐波电压的相位。

$$U_{2I} = \frac{1}{6}\left[u_0 + u_6 - u_3 - u_9 + \frac{1}{2}(u_1 + u_5 + u_7 + u_{11} - u_2 - u_4 - u_8 - u_{10})\right] \tag{17}$$

$$U_{2R} = \frac{\sqrt{3}}{12}\left[u_1 + u_2 + u_7 + u_8 - u_4 - u_5 - u_{10} - u_{11}\right] \tag{18}$$

$$\varphi_u = \arctan\frac{u_{2I}}{u_{2R}} \tag{19}$$

二次谐波电压与二次谐波电流之间的相位差φ为:

$$\varphi = \varphi_u - \varphi_I \tag{20}$$

由于采用人工二次谐波电流, 在正常运行时, 发电机机端电压互感器的开口三角形接线二次电压并不为零, 为了去掉二次谐波电流的影响, 对基波零序电压, 也用富里叶变换从输入信号中抽取基波电压分量, 基波电压富里叶变换公式为:

$$u_I = \frac{2}{N}\left[u_0 - u_6 + \frac{\sqrt{3}}{2}(u_1 - u_5 - u_7 + u_{11}) + \frac{1}{2}(u_2 - u_4 - u_8 + u_{10})\right] \tag{21}$$

(下转59 页)

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.n

也各不相同，缺少一个权威的技术规范指导。不但影响了远传的进一步实用化，对微机故障录波器的发展也很不利。因此，制定相应的微机录波器技术规范，统一录波信息格式，制定录波器远传规约，应是有关技术指导部门目前需要解决的问题，只有这样才能从根本上解决故障录波器的混乱问题，大幅度提高录波完好率。

5 解决统一时钟问题

一旦全面实现录波信息远传，必然要求统一各种信息的时标，在复杂的系统故障情况下，没有时标的录波信息的价值大大降低，因此如何统一录波器的时钟，也是需要解决的问题之一。一方面，要求录波器具有时钟接口，另一方面需要解决统一时钟源。目前不少厂站都安装了 GPS 系统，合理利用这一资源应是解决录波器统一时钟的最佳途径。

6 非技术问题

从电网运行来讲，故障录波器是重要的安全自动装置，但由于它不会去跳开关，所以有些领导和专业人员有意无意把故障录波器放在了次要的位置，至于是否能够把录波信息远传给上级调度运行部门就更加不引起重视了，远传通道的紧张也多少有这方面的原因。因此，加强录波器管理，制定一套有效的考核办法是运行管理部门要研究解决的问题。

(上接 29 页)

$$u_R = \frac{2}{N}\left[u_3 - u_9 + \frac{\sqrt{3}}{2}(u_2 + u_4 - u_8 - u_{10}) + \frac{1}{2}(u_1 + u_5 - u_7 - u_{11})\right] \quad (22)$$

2 结论

本文提出的二次谐波型定子接地保护装置它反应的是二次谐波电压与二次谐波电流之间的相位差，即反应二次谐波回路的阻抗角，因而有较高的灵敏度。它的原理和动作判据与已有的外加 100Hz 交流电源的定子接地保护不大相同，后者反应的是从发电机机端电压互感器开口三角形线圈所得到二次谐波电压 u_u 与从发电机中性点电流互感器得到与零序电流成比例的电压 U_i 的比值 $\frac{u_u}{u_i}$ 的大小。此外本装置还有下面的优点:

(1) 保护非常简单，单片机外围硬件很少，易于实现。

(2) 利用富里叶变换从输入信号中抽取二次谐波电压和电流，或者基波零序电压，因此具有较强的抗干扰能力。

(3) 二次谐波定子接地保护与基波零序电压接地保护一起，可保护定子绕组的 100%。

(4) 由于二次谐波是外加的，它不受运行方式的影响，保护的灵敏度较好。

参考文献

1 王维俭等 . 大型机组继电保护理论基础 . 水利电力出版社，1982

2 李振然 . 利用富里叶变换实现微机自动准同期 . 继电器，1994. 4

3 阎善忠 . 如何利用人工二次谐波分量在中性点经过消弧线圈接地系统中实现单相稳定性接地短路保护 . 继电器，1987. 4

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.n

RELAY

Vol. 25 No. 4 August 1997

CONTENTS AND ABSTRACTS (Partial)

THEORETICAL STUDY AND CALCULATION

The Influence of Capacitance Current to differential Protection and Its Compensation Scheme ..... **Wu Yekai, Zou Dongxia** (4)

The influence of distributed Capacitance of UHV distant transmission line to current differential protection is analyzed and the corresponding capacitance current compensation scheme is presented in this paper. The scheme is simple and practical, not only increasing security during short- circuit beyond protected zone but also improving sensitivity at fault within the protected zone.

Key words: Distributed capacitance Current differential protection Capacitance current compensation

Feasibility Study on Whole Line Fault High Speed Clearing Protection for Distribution Power System ..... **Pan Zhencun et al** (9)

A new concept of whole line fault high speed clearing protection is introduced according to the structure of urban distribution power system and requirement of power supplying. Feasibility study on this protection is carried out. A practical implement scheme of this protection, which measures the electrical signal on both sides of the protected line is presented.

Key words: Distribution power system Line protection High speed relay Feasibility

One Convenient Method for Modifying Bus- Impedance Matrix in Open Circuit State ..... **Wang Chun et al** (12)

The computating formulas for modifying bus- impedance matrix in open circuit state are derived in this paper. They are convenient to calculate and easily programmed. They have been used in fault- calculating program.

Key words: Open circuit fault Bus- impedance matrix Line with zero- sequence mutual impedance

The Method of Deriving Magnetization Curve When Using Magnetic Characteristic to Discriminate Energization Inrush of Transformer ..... **Zhang Yan et al** (16)

A new method of deriving magnetization curve of transformer- - the approximating function optimization is presented to meet the requirement of using magnetic flux characteristic to discriminate the energization inrush current in transformer. Actual calculation shows that the magnetization curve derived by the method is of high accuracy and its error is within 1%, thus it can meet the requirement of transformer differential protection.

Key words: Power transformer Magnetization curve Energization inrush

NEW TECHNICAL RESEARCH AND APPLICATION

Reliability Analysis on The microcomputer Supervisory Control System for Substation by Using Two- Model Redundancy Technology ..... **Sun Ying** (19)

A microcomputer protection and supervisory control system for substation by using the two- model redundancy technology is briefly described. With reference to the system, the reliability of the two- model redundancy system is analyzed and effect of fault- tolerant technique in improving the reliability of the system is also discussed.

Key words: Redundancy Fault- tolerant Substation Microcomputer supervisory control

A New Method to Realize the Digital Impedance Relay ..... **Jin Ming** (22)

A new method to realize the digital impedance relay based on microcomputer is described in this paper. The new method utilizes ANN (artificial neural network) and is available for all kinds of relay characteristics which are used in power system. Some examples are used to test the new algorithm and the results show the algorithm performs well.

Key words: ANN Impedance relay Distance protection

Microcomputer Based Single Phase Earthed Protection of Generator stator Winding of Secondary Harmonic Mould ..... **Yan Zhuosheng et al** (26)

A single phase earthed protection of generator stator winding is presented in this paper. It is realized by de-

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.n

tecting the phase difference between secondary harmonic voltage and secondary harmonic current. Artificial secondary harmonic current is put into secondary coil of electrical arc elimination coil of generator neutral protection. This protection can constitute 100% protective range with the fundamental wave zero sequence voltage protection.
Key words: Single phase earthed protection of generator stator winding Secondary harmonic Fourier transformation
Application of PLC in stability Conyrol of Power System ····· **Lu Guanghui et al**(30)
The application of PLC in stability control of power system is described with reference to the local interlocked generator cut off device. The detailed scheme, software and hardware are presented. Advantages and feasibility of the PLC used as automatic control device in stability control of power system are discussed. PQJ- 1 interlocked generator cut- off system which is composed of PLC is especially available to the water power station with distant and heavy loads.
Key words: Stability control Interlocked generator cut- off system PLC
New Intelligent Microcomputer- Based Protection Debugging Apparatus ····· **Chao Qin et al**(34)
The hardware structure, software design principle, function and features of a new intelligent protection debugging apparatus, which is based on a MCS 8098 single- chip microcomputer, are described in this paper. The apparatus can provide in realtime the electric current and voltage transient waveforms of various fault cases in power system and the system static signals to protective device according to the operating signal and process of the device. It can replace the expensive dynamic modelling laboratory to carry out the debugging of HF and distance protections and the static and dynamic modelling tests of whole protection. It features small size and low price, and is especially available for field debugging and testing.
Key words: Microcomputer protection Sigle- chip microcomputer Debugging apparatus Software
Development And Application of On- Line Fault Monitor for DC System of Power Generating Plant
····· **Cui Shi et al** (36)
The working principle and struture of an on- line fault monitor for dc system are described in this paper. When an one- point or multi- point earth fault occurs, the monitor can quickly detect the serial number and polarity of the branch circuit earthed, and meantime give alarm to the operator on site. It has been put in operation in the second power plant of Jiamusi.
Key words: DC system On- line Monitor Earth
Characteristic And Testing of Microcomputer Protective Relay for LV Network ····· **Li Renjun et al** (40)

TECHNICAL IMPROVEMENT

Consideration on Technical Improvement Design of Substation without Operator on Duty
····· **Chen Yuanpeng**(46)
Improvement Design of Current Phase Comparison Type Bus Differential Protection ····· **Zhao Xuejun**(51)
The advanteges and shortcomings of current phase comparison type bus differential protection are presented in this paper and the suggestion is made to improve design.
Key words: Bus differential protection Improvement Suggestion

SITE EXPERIENCE

Analysis on Maloperation Event of Bus Protection of Guizhou Qingzhen Power Plant on November 15, 1996
····· **Cheng Lijun**(54)
Several Questions on Complete Realization of Microcomputer- Based Fault Recorder Signal Remote Transfer
····· **Sun Yueqin**(58)

STRUCTURE AND TECHNOLOGY

Discussion on Two Connection Methods of Terminal ····· **Zou Xiuyun**(60)
In electrical connection, using terminal as transition connection is a more general method. In various terminal structures of China, the two methods of plate pressure connection and sleeve pressure connection are often used. By analysis and comparison between the two methods, some shortcomings of plate pressure connection method are shown and the connection method of sleeve structure is recommended.
Key words: Terminal Connection Electrical connection

English editor: Zhang Zhiqiang

© 1994-2008 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.n