

PILOT WIRE DIFFERENTIAL PROTECTION APPARATUS FOR MULTI-END CIRCUIT BASED ON PHASE COMPARISON PRINCIPLE

TECHNICAL FIELD

[0001] The present invention relates to a protection apparatus and method for power transmission and distribution lines in a middle/short distance. In particular, the present invention relates to a pilot wire differential protection apparatus and method for multi-end circuit based on a phase comparison principle.

BACKGROUND

[0002] As a protection apparatus for power transmission and distribution lines in the middle/short distance, a TRANSLAY relay manufactured, for example, by General Electric Company (GEC) in UK or similar products manufactured by other companies may be utilized to form the pilot wire differential protection apparatus. The TRANSLAY relay utilizes a phase comparator to form a judgment element and thus has excellent properties.

[0003] Fig.1 is a view illustrating main structure of the TRANSLAY relay. Respective elements in the Fig.1 are: a summation transformer T_I , a secondary winding T_t , a secondary winding T_s , an auxiliary transformer T_{II} , an operating winding T_o , a restraining winding T_r , a non-linear resistor RVD, a linear impedance R_o , a pilots padding resistor R_{pp} , a phase comparator Φ . I_a , I_b , I_c and I_n are currents in an a phase, a b phase, a c phase and a neutral point of a protected circuit end, respectively. P_x and P_y are two terminals connecting with the pilot wires.

[0004] The summation transformer T_I is used for transforming three-phase currents into a single-phase summated current. The secondary winding T_t is used for providing one phase comparison voltage. The secondary winding T_s is used for outputting the single-phase summated current at the secondary side of the summation transformer T_I . An output circuit of the auxiliary transformer T_{II} is used for providing the other phase comparison voltage. The operating winding T_o is used for providing an operation current of protection. The restraining winding T_r is used for providing a restraining current of protection. A difference between the operating current and the restraining current is a protection start current. The non-linear

resistor RVD is used for voltage stabilization. The linear impedance R_o is a linear impedance on a single-phase summated current loop at the secondary side. The pilots padding resistor R_{pp} is used for matching a total resistor in a pilot wire loop to a set value, and an aim of the matching is to perform adjustment so as to remain the total resistor unchanged, since the total resistor on the pilot wire must be fixed and preset according to a TRANSLAY pilot wire protection principle. The phase comparator Φ is used for comparing phases of two voltages and judging an in-zone/out-zone fault based on the phase difference between the two comparison voltages, wherein the phase comparator is an analogous phase comparator or a digital phase comparator. A protecting mechanism will be triggered when the start current is greater than a set threshold value and it is judged as the in-zone fault by the phase comparator.

[0005] However, both a wiring manner and an action equation of a current pilot wire longitudinal differential protection apparatus composed of the TRANSLAY relays are based on a protection for the two-end circuit and therefore can only be applied to protect the two-end circuit. Unfortunately, no protection apparatus or method based on the TRANSLAY relays is proposed for the multi-end circuit in the lines of the power transmission and distribution.

[0006] In view of the above disadvantages in the prior art, the present invention proposes a pilot wire differential phase-compared apparatus and method being applicable to the multi-end circuit, which may extend a usage range of the TRANSLAY relay.

SUMMARY

[0007] An object of the present invention is to make up the disadvantages existed in the current pilot wire differential phase-compared protection apparatus and method for the power transmission and distribution lines based on the TRANSLAY relay and to provide a pilot wire differential phase-compared apparatus and method for the power transmission and distribution lines based on the TRANSLAY relay, which may be applied to the multi-end circuit.

[0008] According to an aspect of the present invention, there is provided a pilot wire differential protection apparatus for a power transmission and distribution lines including

three or more connecting ends, comprising:

[0009] three or more TRANSLAY relays, which are sequentially connected at the corresponding connecting ends of the power transmission and distribution lines, respectively,

[0010] wherein summation transformers of the respective TRANSLAY relays are connected to an a phase, a b phase, a c phase and a neutral point at the connecting ends of the corresponding protected circuits, and a pilot wire first connecting terminal and a pilot wire second connecting terminal of the respective TRANSLAY relays are connected with each other in parallel, respectively,

[0011] wherein the TRANSLAY relays comprise corresponding phase comparators, respectively, for comparing corresponding phases of U_I and U_{II} in the respective TRANSLAY

relays so as to obtain a corresponding phase difference $\text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}}$, wherein U_I is a voltage at

one side of the phase comparator, that is, a voltage at a secondary winding side of the relay, U_{II} is a voltage of the other side of the phase comparator, that is, a voltage at a auxiliary transformer side of the relay, and a false state of the power transmission and distribution lines

is judged according to the corresponding phase differences $\text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}}$,

[0012] wherein, at each of the connecting ends, a pilots padding resistor R_{pp} of the respective TRANSLAY relay is adjusted so that $R_{pp} + R_w = k * R_0$ is satisfied at each of the ends, k is a set constant, R_w is a resistance on the pilot wire, and R_0 is a linear impedance of the TRANSLAY relay,

[0013] wherein a value of k satisfies a condition of $-n * k - 1 < -1 < -(n * k + n) * T_0 / Tr + n - 1$ when $T_0 < Tr$, or the value of k satisfies a condition of $-(n * k + n) * T_0 / Tr + n - 1 < -1 < -n * k - 1$ when $T_0 > Tr$, T_0 is number of turns of an operating winding in the TRANSLAY relay and Tr is number of turns of a restraining winding in the TRANSLAY relay.

[0014] It is judged that a system of the power transmission and distribution lines is in an in-zone fault state and the pilot wire differential protection apparatus is triggered to

perform protection, when at least one of the phase differences in the phase comparators of the respective TRANSLAY relays does not satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ and a start current of the relay is greater than a set threshold value.

[0015] It is judged that the system of the power transmission and distribution lines is in a normal operation state or an out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$.

[0016] The phase comparator is an analogous phase comparator or a digital phase comparator.

[0017] According to another aspect of the present invention, there is provided a method for a pilot wire differential protection apparatus, comprising steps of:

[0018] measuring phases of corresponding U_I and U_{II} of respective TRANSLAY relays, wherein U_I is a voltage at one side of the phase comparator, that is, a voltage at a secondary winding side of the relay, and U_{II} is a voltage of the other side of the phase comparator, that is, a voltage at a auxiliary transformer side of the relay;

[0019] comparing, by corresponding phase comparators in the TRANSLAY relays, the phases of U_I and U_{II} in the respective TRANSLAY relays so as to obtain a corresponding phase difference $\text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}}$; and

[0020] judging a false state of the power transmission and distribution lines according to the corresponding phase differences $\text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}}$,

[0021] wherein, at each of the connecting ends, a pilots padding resistor R_{pp} of the respective TRANSLAY relay is adjusted so that $R_{pp} + R_w = k * R_0$ is satisfied at each of the ends, k is a set constant, R_w is a resistor on the pilot wire, and R_0 is a linear impedance of the TRANSLAY relay,

[0022] wherein a value of k satisfies a condition of $-n * k - 1 < -1 < -(n * k + n) * T_0 / T_r + n - 1$ when $T_0 < T_r$, or the value of k satisfies a

condition of $-(n * k + n) * T_0 / Tr + n - 1 < -1 < -n * k - 1$ when $To > Tr$, To is number of turns of an operating winding in the TRANSLAY relay and Tr is number of turns of a restraining winding in the TRANSLAY relay.

[0023] It is judged that a system of the power transmission and distribution lines is in an in-zone fault state and the pilot wire differential protection apparatus is triggered to perform protection, when at least one of the phase differences in the phase comparators of the respective TRANSLAY relays does not satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ and a start current of the relay is greater than a set threshold value.

[0024] It is judged that the system of the power transmission and distribution lines is in a normal operation state or an out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$.

[0025] The phase comparator is an analogous phase comparator or a digital phase comparator.

[0026] The pilot wire differential phase-compared apparatus and method of the present invention which are applicable to the multi-end circuit extend a usage range of the TRANSLAY relay.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] The present invention will become more fully understood from the detailed description of the exemplary embodiments given hereinafter in connection with accompanying drawings. It should be understood that the described embodiments are given by way of illustration and example only, and the present invention is not limited thereto. The spirit and scope of the present invention are defined by contents stated in the accompanying claims attached. Below is a brief description for the drawings and wherein:

[0028] Fig 1 is a diagram illustrating a main structure of the TRANSLAY relay;

[0029] Fig 2 is an exemplary view illustrating a wiring in a pilot wire differential phase-compared protection apparatus applied to a three-end circuit according to a first

embodiment of the present invention;

[0030] Fig 3 is an equivalent circuit diagram for the pilot wire differential phase-compared protection apparatus applied to the three-end circuit according to the first embodiment of the present invention;

[0031] Fig 4 is a motion trajectory of a differential protection for the pilot wire differential phase-compared protection apparatus applied to the three-end circuit according to the first embodiment of the present invention;

[0032] Fig 5 is an exemplary view illustrating a wiring in a pilot wire differential phase-compared protection apparatus applied to a multi-end circuit according to a second embodiment of the present invention;

[0033] Fig 6 is an equivalent circuit diagram for the pilot wire differential phase-compared protection apparatus applied to the multi-end circuit according to the second embodiment of the present invention;

[0034] Fig 7 is a motion trajectory of a differential protection for the pilot wire differential phase-compared protection apparatus applied to the multi-end circuit according to the second embodiment of the present invention.

DETAILED DESCRIPTION

[0035] The pilot wire differential phase-compared protection apparatus and method according to the present invention will be explained now with reference to the accompany drawings.

[0036] Fig 2 is an exemplary view illustrating a wiring in a pilot wire differential phase-compared protection apparatus applied to a three-end circuit according to a first embodiment of the present invention.

[0037] Three sets of TRANSLAY relays Relay1, Relay2, Relay3 are connected at the end 1, end 2, end 3 of the power transmission and distribution lines, respectively, summation transformers T_1 of the respective TRANSLAY relays Relay1, Relay2, Relay3 are connected to an a phase, a b phase, a c phase and a neutral point at the protected circuit end, and pilot wire connecting terminals Px and Py of the respective TRANSLAY relays Relay1, Relay2, Relay3 are connected with each other at nodes j1 and j2 in parallel, respectively.

[0038] In the above connection, configurations of each set of the TRANSLAY relays at the end 1, end 2, end 3 should be same completely. That is, all of other elements and parameters in the relays illustrated in Fig 1 are the same without considering errors, other than the R_{pp} . The connections and configurations at the three ends are same, therefore the three ends are symmetrical completely.

[0039] Thus an equivalent circuit diagram for the pilot wire differential phase-compared protection apparatus applied to the three-end circuit according to the first embodiment of the present invention shown in Fig 2 may be illustrated as Fig 3. R_w is a resistance on the pilot wire in Fig 3.

[0040] At each of the ends, a resistor R_{pp} of the respective TRANSLAY relay is adjusted so that $R_{pp} + R_w = k * R_0$ is satisfied at each of the ends, k is a set constant.

[0041] According to the structure of the TRANSLAY relay, by making the protection at the relay Relay1 end as an example, currents flowing through the To, Tr and Ro of the Relay1 may be calculated as follows, respectively, from Fig 3: $\dot{I}_1$, $((3-1)*\dot{I}_1 - (\dot{I}_2 + \dot{I}_3))/(3*k+3)$ and $((3*k+1)*\dot{I}_1 + (\dot{I}_2 + \dot{I}_3))/(3*k+3)$, wherein $\dot{I}_1$, $\dot{I}_2$ and $\dot{I}_3$ are current flowing through the To of the Relay1, current flowing through the To of the Relay2 and current flowing through the To of the Relay3, respectively.

[0042] According to a design principle of the TRANSLAY relay, voltages at the windings Tt and Ts are in-phase, and voltage on the Ro is approximatively same as that on the Ts, therefore a voltage at the Tt side of the phase comparator satisfies an equation (1), wherein K_I is a calculation constant.

[0043]
$$\dot{U}_I = K_I * ((3*k+1)*\dot{I}_1 + (\dot{I}_2 + \dot{I}_3)) \quad (1)$$

[0044] A voltage at the TII side of the phase comparator is decided by two primary windings To and Tr and satisfies an equation (2), wherein K_{II} is a calculation constant.

[0045]
$$\dot{U}_{II} = K_{II} * (((3*k+3)*T_0/Tr - 3+1)*\dot{I}_1 + (\dot{I}_2 + \dot{I}_3)) \quad (2)$$

[0046] Given $\dot{\rho}_1 = \frac{\dot{I}_2 + \dot{I}_3}{\dot{I}_1}$, which is a current ratio between the sum of current

vectors in remote ends and the current in local end, then:

$$[0047] \quad 90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} = \text{Arg} \frac{\dot{\rho}_1 - (-3*k - 1)}{\dot{\rho}_1 - (-3*k + 3)*T_0/Tr + 3 - 1} \geq -90^\circ \quad (3)$$

[0048] Assuming a value of k selected suitably, that is, the value of k satisfies a condition of $-3*k - 1 < -1 < -(3*k + 3)*T_0/Tr + 3 - 1$ when $To < Tr$, or the value of k satisfies a condition of $-(3*k + 3)*T_0/Tr + 3 - 1 < -1 < -3*k - 1$ when $To > Tr$, a region corresponding to the current ratio between the sum of current vectors in remote ends and the current in local end in the equation (3) is circular on a complex plane. Fig 4 is a motion trajectory of a differential protection for the pilot wire differential phase-compared protection apparatus applied to the three-end circuit according to the first embodiment of the present invention.

[0049] When the system operates normally or has an out-zone fault, $\dot{\rho}_1 = \frac{\dot{I}_2 + \dot{I}_3}{\dot{I}_1}$ is

-1 under ideal conditions, therefore a portion inside the circle corresponding to the ρ_1 is a restraining zone or stable zone.

[0050] Further, when the system has an in-zone fault, a portion outside the circle corresponding to the ρ_1 is an operating zone.

[0051] Thus the in-zone fault and the out-zone fault may be judged by comparing the phases of U_I and U_{II} .

[0052] In particularly, in an actual application, when $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$, the system operates normally or is in the out-zone fault state; if $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is not satisfied and a start current of the relay is greater than a set threshold value, the system is in the in-zone fault state.

[0053] That is, it is judged whether the $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is satisfied if fault

occurs in the system: it is the in-zone fault if the $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is not satisfied and

the start current of the relay is greater than the set threshold value; and it is the out-zone fault if the $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is satisfied.

[0054] Above descriptions are made by taking the relay Relay1 end as an example, and the phase differences between the U_I and U_{II} in the Relay2 and Relay3 also can be used to make judgment. The phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3 are independent of each other.

[0055] It is also obviously that, when the system operates normally or has the out-zone fault, $\dot{\rho}_1 = \frac{\dot{I}_2 + \dot{I}_3}{\dot{I}_1}$, $\dot{\rho}_2 = \frac{\dot{I}_1 + \dot{I}_3}{\dot{I}_2}$,, $\dot{\rho}_3 = \frac{\dot{I}_1 + \dot{I}_2}{\dot{I}_3}$ are -1 under the ideal conditions, therefore portions inside the circles corresponding to the respective ρ are the restraining zones or stable zones. Further, when the system has the in-zone fault, portions outside the circles corresponding to the respective ρ are the operating zones.

[0056] It is judged that the system is in an in-zone fault state, when at least one of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3 does not satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ and the start current of the relay is greater than the set threshold value.

[0057] It is judged that the system is in a normal operation state or an out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3 satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$.

[0058] When the system is in the in-zone fault state, the pilot wire differential protection apparatus for the three-end power transmission and distribution lines is triggered to perform the protection.

[0059] Fig 5 is an exemplary view illustrating a wiring in a pilot wire differential phase-compared protection apparatus applied to a multi-end circuit according to a second embodiment of the present invention.

[0060] In Fig 5, a plurality of sets of TRANSLAY relays Relay1, Relay2, Relay3,, Relayn are connected at the end 1, end 2,, end n of the power

transmission and distribution lines, respectively, the summation transformers T_1 of the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relay n are connected to an a phase, a b phase, a c phase and a neutral point at the protected circuit end, and pilot wire connecting terminals Px and Py of the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relay n are connected with each other in parallel, respectively.

[0061] In the above connection, configurations of each set of the TRANSLAY relays at the end 1, end 2,, end n should be same completely. That is, all of other elements and parameters in the relays illustrated in Fig 1 are the same without considering errors, other than the R_{pp} . The connections and configurations at the plurality of ends are same, therefore the plurality of ends are symmetrical completely.

[0062] Thus an equivalent circuit diagram for the pilot wire differential phase-compared protection apparatus applied to the multi-end circuit according to the second embodiment of the present invention shown in Fig 5 may be illustrated as Fig 6. R_w is a resistance on the pilot wire in Fig 6.

[0063] At each of the ends, a resistor R_{pp} of the respective TRANSLAY relay is adjusted so that $R_{pp} + R_w = k * R_0$ is satisfied at each of the ends, k is a set constant, and the values of k in each of the TRANSLAY relays are identical.

[0064] According to the structure of the TRANSLAY relay, by making the protection at the relay Relay1 end as an example, currents flowing through the To, Tr and Ro of the Relay1 may be calculated as follows, respectively, from Fig 6: $\dot{I}_1$, $((n-1) * \dot{I}_1 - (\dot{I}_2 + \dots + \dot{I}_n)) / (n * k + n)$ and $((n * k + 1) * \dot{I}_1 + (\dot{I}_2 + \dots + \dot{I}_n)) / (n * k + n)$.

[0065] According to the design principle of the TRANSLAY relay, voltages at the windings Tt and Ts are in-phase, and voltage on the Ro is approximatively same as that on the Ts, therefore a voltage at the Tt side of the phase comparator satisfies an equation (4), wherein K_I is a calculation constant.

[0066]
$$\dot{U}_I = K_I * ((n * k + 1) * \dot{I}_1 + (\dot{I}_2 + \dots + \dot{I}_n)) \quad (4)$$

[0067] A voltage at the TII side of the phase comparator is decided by two primary windings To and Tr and satisfies an equation (5), wherein K_{II} is a calculation constant.

[0068]
$$\dot{U}_{II} = K_{II} * (((n * k + n) * T_0 / Tr - n + 1) * \dot{I}_1 + (\dot{I}_2 + \dots + \dot{I}_n)) \quad (5)$$

[0069] Given $\dot{\rho}_1 = \frac{\dot{I}_2 + \dots + \dot{I}_n}{\dot{I}_1}$, which is a current ratio between the sum of current

vectors in remote ends and the current in local end, then:

[0070]
$$90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} = \text{Arg} \frac{\dot{\rho}_1 - (-n * k - 1)}{\dot{\rho}_1 - (-(n * k + n) * T_0 / Tr + n - 1)} \geq -90^\circ \quad (6)$$

[0071] Assuming a value of k selected suitably, that is, the value of k satisfies a condition of $-n * k - 1 < -1 < -(n * k + n) * T_0 / Tr + n - 1$ when $T_0 < Tr$, or the value of k satisfies a condition of $-(n * k + n) * T_0 / Tr + n - 1 < -1 < -n * k - 1$ when $T_0 > Tr$, a region corresponding to the current ratio between the sum of current vectors in remote ends and the current in local end in the equation (6) is circular on a complex plane, as illustrated in Fig 7.

[0072] Fig 7 is a motion trajectory of a differential protection for the pilot wire differential phase-compared protection apparatus applied to the three-end circuit according to the first embodiment of the present invention.

[0073] When the system operates normally or has an out-zone fault, $\dot{\rho}_1 = \frac{\dot{I}_2 + \dots + \dot{I}_n}{\dot{I}_1}$ is -1 under ideal conditions, therefore a portion inside the circle

corresponding to the ρ_1 is a restraining zone or stable zone.

[0074] Further, when the system has an in-zone fault, a portion outside the circle corresponding to the ρ_1 is an operating zone.

[0075] Thus the in-zone fault and the out-zone fault may be judged by comparing the phases of U_I and U_{II} .

[0076] In particularly, in an actual application, when $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$, the

system operates normally or is in the out-zone fault state; if $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is not

satisfied and a start current of the relay is greater than a set threshold value, the system is in the in-zone fault state.

[0077] That is, it is judged whether the $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is satisfied if fault occurs in the system: it is the in-zone fault if the $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is not satisfied and the start current of the relay is greater than the set threshold value; and it is the out-zone fault if the $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ is satisfied.

[0078] Above descriptions are made by taking the relay Relay1 end as an example, and the phase differences between the U_I and U_{II} in the Relay2, Relay3,, Relayn also can be used to make judgment. The phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relayn are independent of each other.

[0079] It is also obviously that, when the system operates normally or has the out-zone fault, $\dot{\rho}_1 = \frac{\dot{I}_2 + \dots + \dot{I}_n}{\dot{I}_1}$, $\dot{\rho}_2 = \frac{\dot{I}_1 + \dot{I}_3 + \dots + \dot{I}_n}{\dot{I}_2}$,, $\dot{\rho}_n = \frac{\dot{I}_1 + \dot{I}_2 + \dots + \dot{I}_{n-1}}{\dot{I}_n}$ are -1 under the ideal conditions, therefore portions inside the circles corresponding to the respective ρ are the restraining zones or stable zones. Further, when the system has the in-zone fault, portions outside the circles corresponding to the respective ρ are the operating zones.

[0080] It is judged that the system is in the in-zone fault state, when at least one of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relayn does not satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ and the start current of the relay is greater than the set threshold value.

[0081] It is judged that the system is in the normal operation state or the out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relayn satisfy $90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$.

[0082] When the system is in the in-zone fault state, the pilot wire differential protection apparatus for the three-end power transmission and distribution lines is triggered to perform the protection.

[0083] Thereafter will describe a method for the pilot wire differential phase-compared protection apparatus according to the first embodiment and the second embodiment of the present invention.

[0084] The pilot wire differential phase-compared protection method according to the present invention is applied to the above power transmission and distribution lines having three-end or multi-end connection. Following description is made by taking the pilot wire differential phase-compared protection apparatus applied to the multi-end circuit according to the second embodiment of the present invention as an example.

[0085] At step 1, measuring the phases of the voltage U_I at the T_I side of the phase comparator and the voltage U_{II} at the T_{II} side of the phase comparator in the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relayn;

[0086] at step 2, comparing the phases of U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relayn so as to obtain the respective phase differences

$$\text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}};$$

[0087] at step 3, judging whether the phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2, Relay3,, Relayn satisfy

$$90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ.$$

[0088] It is judged that the system operates normally or is in the out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays

$$\text{Relay1, Relay2, Relay3,, Relayn satisfy } 90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ.$$

[0089] It is judged that the system is in the in-zone fault state, when at least one of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays Relay1, Relay2,

$$\text{Relay3,, Relayn does not satisfy } 90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ \text{ and the start current of the relay}$$

is greater than the set threshold value.

[0090] At step 4, the pilot wire differential protection apparatus for the multi-end power transmission and distribution lines is triggered to perform protection when the system

is in the in-zone fault state.

[0091] The pilot wire differential phase-compared apparatus and method of the present invention which are applied to the multi-end circuit can judge the in-zone fault and out-zone fault in the multi-end circuit efficiently, extends an application range of the TRANSLAY protection apparatus and enhance a market value of the TRANSLAY protection apparatus.

[0092] Although the exemplary embodiments considered in the invention has been illustrated and described, those skilled in the art may understand that many changes and amendments may be made or some elements may be replaced with other equivalences without departing from the real scope of the invention, with developments in the technique.

WHAT IS CLAIMED IS:

1. A pilot wire differential protection apparatus for a power transmission and distribution lines including three or more connecting ends, comprising:

three or more TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn), which are sequentially connected at the corresponding connecting ends (end 1, end 2,, end n) of the power transmission and distribution lines, respectively,

wherein summation transformers of the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) are connected to an a phase, a b phase, a c phase and a neutral point at the connecting ends of the corresponding protected circuits, and a pilot wire first connecting terminal and a pilot wire second connecting terminal of the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) are connected with each other in parallel, respectively,

wherein the TRANSLAY relays comprise corresponding phase comparators, respectively, for comparing corresponding phases of U_I and U_{II} in the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) so as to obtain a corresponding phase difference

$Arg \frac{\dot{U}_I}{\dot{U}_{II}}$, wherein U_I is a voltage at one side of the phase comparator, that is, a voltage at a

secondary winding side of the relay, U_{II} is a voltage of the other side of the phase comparator, that is, a voltage at a auxiliary transformer side of the relay, and a false state of the power transmission and distribution lines is judged according to the corresponding phase differences

$Arg \frac{\dot{U}_I}{\dot{U}_{II}}$,

wherein, at each of the connecting ends, a pilots padding resistor R_{pp} of the respective TRANSLAY relay is adjusted so that $R_{pp} + R_w = k * R_0$ is satisfied at each of the ends, k is a set constant, R_w is a resistance on the pilot wire, and R_0 is a linear impedance of the TRANSLAY relay,

wherein a value of k satisfies a condition of $-n * k - 1 < -1 < -(n * k + n) * T_0 / T_r + n - 1$ when $T_0 < T_r$, or the value of k satisfies a condition of

$-(n * k + n) * T_0 / Tr + n - 1 < -1 < -n * k - 1$ when $To > Tr$, To is number of turns of an operating winding in the TRANSLAY relay and Tr is number of turns of a restraining winding in the TRANSLAY relay.

2. The pilot wire differential protection apparatus of claim 1, wherein,

it is judged that a system of the power transmission and distribution lines is in an in-zone fault state and the pilot wire differential protection apparatus is triggered to perform protection, when at least one of the phase differences in the phase comparators of the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) does not satisfy

$$90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ \text{ and a start current of the relay is greater than a set threshold value.}$$

3. The pilot wire differential protection apparatus of claim 1, wherein,

it is judged that the system of the power transmission and distribution lines is in a normal operation state or an out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) satisfy

$$90^\circ \geq \text{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ .$$

4. The pilot wire differential protection apparatus of claim 1, wherein,

the phase comparator is an analogous phase comparator or a digital phase comparator.

5. A method for a pilot wire differential protection apparatus of claim 1, comprising steps of:

measuring phases of corresponding U_I and U_{II} of respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn), wherein U_I is a voltage at one side of the phase comparator, that is, a voltage at a secondary winding side of the relay, and U_{II} is a voltage of the other side of the phase comparator, that is, a voltage at a auxiliary transformer side of the relay;

comparing, by corresponding phase comparators in the TRANSLAY relays, the phases of

U_I and U_{II} in the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) so as to obtain a corresponding phase difference $Arg \frac{\dot{U}_I}{\dot{U}_{II}}$; and

judging a false state of the power transmission and distribution lines according to the corresponding phase differences $Arg \frac{\dot{U}_I}{\dot{U}_{II}}$,

wherein, at each of the connecting ends, a pilots padding resistor R_{pp} of the respective TRANSLAY relay is adjusted so that $R_{pp} + R_w = k * R_0$ is satisfied at each of the ends, k is a set constant, R_w is a resistance on the pilot wire, and R_0 is a linear impedance of the TRANSLAY relay,

wherein a value of k satisfies a condition of $-n * k - 1 < -1 < -(n * k + n) * T_0 / Tr + n - 1$ when $To < Tr$, or the value of k satisfies a condition of $-(n * k + n) * T_0 / Tr + n - 1 < -1 < -n * k - 1$ when $To > Tr$, To is number of turns of an operating winding in the TRANSLAY relay and Tr is number of turns of a restraining winding in the TRANSLAY relay.

6. The method for the pilot wire differential protection apparatus of claim 5, wherein, it is judged that a system of the power transmission and distribution lines is in an in-zone fault state and the pilot wire differential protection apparatus is triggered to perform protection, when at least one of the phase differences in the phase comparators of the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) does not satisfy $90^\circ \geq Arg \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^\circ$ and a start current of the relay is greater than a set threshold value.

7. The method for the pilot wire differential protection apparatus of claim 5, wherein, it is judged that the system of the power transmission and distribution lines is in a normal operation state or an out-zone fault state when all of the phase differences between the U_I and U_{II} in the respective TRANSLAY relays (Relay1, Relay2, Relay3,, Relayn) satisfy

$$90^{\circ} \geq \operatorname{Arg} \frac{\dot{U}_I}{\dot{U}_{II}} \geq -90^{\circ}.$$

8. The method for the pilot wire differential protection apparatus of claim 5, wherein, the phase comparator is an analogous phase comparator or a digital phase comparator.