Protection Scheme for Special Railway Transformers with RET 521

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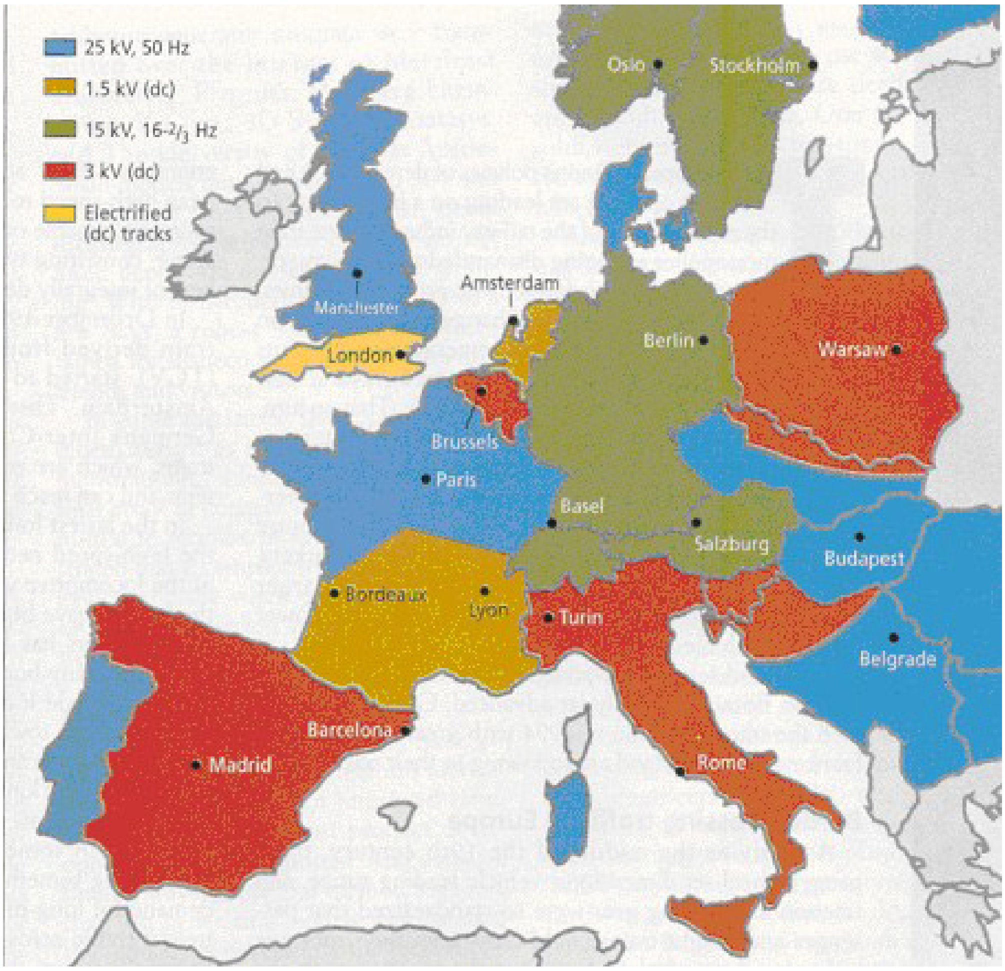
Introduction

With RET 521, it is possible to protect special types of railway transformers. However it should be noted that RET 521 can be only used in 50Hz or 60Hz railway supply systems (i.e. it can not be used for protection in railway supply system with frequency of $16\frac{2}{3}Hz$). The following picture gives an overview about different railway electrical supply systems traditionally used in Europe.



50Hz or 60Hz railway supply system is used in other parts of the world as well (i.e. Russia, Turkey, China, Korea, Australia etc.). It is often used in new railway electrification projects all over the world (for example in Italy, Korea, France etc.).

It is important to understand that RET 521 can offer, not only transformer differential protection, but also complete protection and control scheme for railway transformers.

It should be noted as well, that with 500 series of products (i.e. control terminal REC 561, railway distance protection terminal REO 517, transformer protection terminal RET 521 & busbar protection terminal RED 521) ABB can offer complete Substation Automation Protection and Control System for 50Hz or 60Hz railway supply system.

Standard Features in RET 521

RET 521 is primarily designed for protection and control of three-phase power transformers in transmission and distribution electricity power supply networks. Since its introduction in 1998, more than one thousand units were supplied worldwide. It is used for protection of power transformers with rating of up to and including 1000MVA, 500kV.

RET 521 is multifunctional power transformer protection and control terminal, which can include the following protection, control and monitoring functions:

- Differential protection for two or three winding power transformer with built-in 2nd harmonic block, 5th harmonic block and wave-block features (ANSI No 87T, 87H)
- Restricted earth fault protection functions (ANSI No 87N)
- Three-phase time overcurrent protection functions (ANSI No 50, 51)
- Single-phase time overcurrent protection functions (earth fault protection) (ANSI No 50N/51N, 50G/51G)
- Thermal overload protection function (ANSI No 49)
- Time overvoltage protection functions (ANSI No 59)
- Time undervoltage protection functions (ANSI No 27)
- Overexcitation (V/Hz) protection function (ANSI No 24)
- Automatic voltage control function (automatic on-load tap-changer control) (ANSI No 90)
- Disturbance recording for ten analogue signals with 1ms resolution
- Disturbance recording for 48 binary signals with 1ms resolution

RET 521 is fully numerical protection terminal. Twenty samples in each power system cycle (i.e. 1000Hz sampling rate for 50Hz power system, 1200Hz sampling rate for 60Hz power system) are used for all internal algorithms including transformer differential protection. By efficient digital filtering, phasors of the fundamental frequency component are extracted and used in all protection and control algorithms. Therefore any dc component and all higher order harmonics in the current and voltage input signals are effectively suppressed. Hence they do not influence much on the operation and the accuracy of any protection or control function in RET 521.

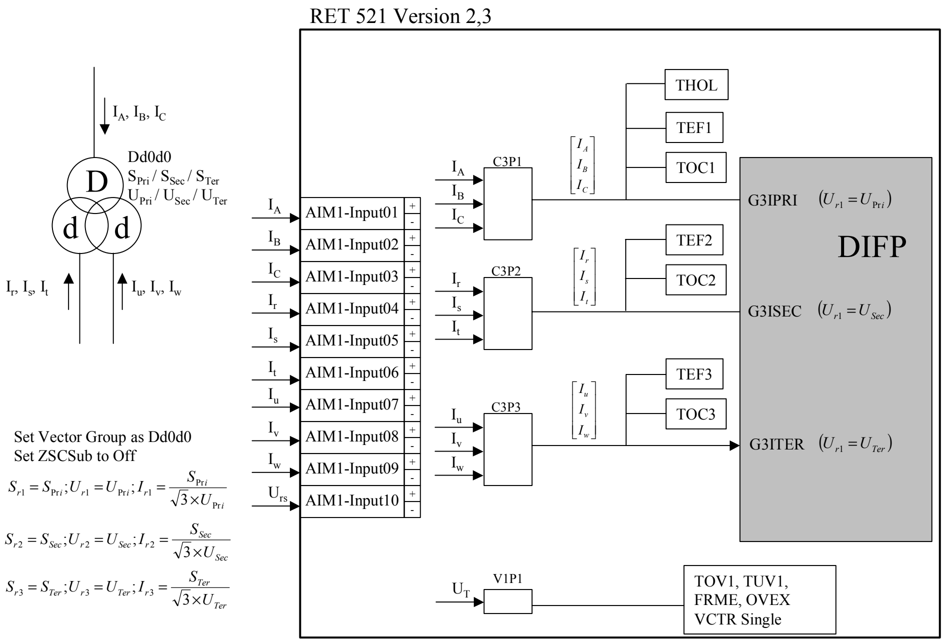
All calculations inside RET 521 are done in primary amperes and volts. Therefore it is of outmost importance that all CT & VT data (i.e. ratios and grounding) are properly set. For the railway applications CT and VT data need to be set in the same way as for the normal three-phase power transformer.

In RET 521 is necessary to set "Power Transformer Rated Data". Under these settings the user have to enter rated power, rated current and rated voltage for every winding of the three-phase power transformer. All protection and control functions in RET 521 in one or another way use these set values. For all railway application these data need to be set in a special way because the railway transformers are not of a three-phase design. However in this document is clearly shown how this data need to be set for each specific railway transformer type.

Protection Scheme for Three-Phase, Dd0d0 Power Transformer

First let's explain a protection scheme for "normal" three-phase power transformer in order to understand how the differential currents are calculated within the RET 521 terminal. For this example it is possible to use RET 521 for the complete transformer protection scheme as shown on the following figure:

Protection of 3Ph Dd0d0 Power Transformer



$$S_{r1} = S_{Pri}; U_{r1} = U_{Pri}; I_{r1} = \frac{S_{Pri}}{\sqrt{3} \times U_{Pri}}$$

$$S_{r2} = S_{Sec}; U_{r2} = U_{Sec}; I_{r2} = \frac{S_{Sec}}{\sqrt{3} \times U_{Sec}}$$

$$S_{r3} = S_{Ter}; U_{r3} = U_{Ter}; I_{r3} = \frac{S_{Ter}}{\sqrt{3} \times U_{Ter}}$$

In the same time this figure shows the required analogue quantities which needs to be measured as well as the analogue part of the configuration which need to be made in the CAP tool for this particular application. In this case the following functions can be included:

Function in RET	**What-for the function is used in configuration**
DIFP (3-winding)	Bias differential function for the transformer (87T & 87H)
TOC1	HV overcurrent (50/51)
TEF1	HV earth-fault (50N/51N)
TOC2	MV overcurrent (50/51)
TEF2	MV earth-fault (50N/51N)
TOC3	LV overcurrent (50/51)
TEF3	LV earth-fault (50N/51N)
THOL	HV Thermal overload (49)
FRME	Frequency measurement
TOV1	LV Overvoltage (59)
TUV1	LV Undervoltage (27)
OVEX	Overexcitation (not commonly used in railway applications) (24)
VCTR	Voltage control for transformer with OLTC (90)
DRxx	Disturbance Recorder function for 10 analogue & 48 binary channels

It can be shown that for this particular setup and settings for ZSCSub=”Off”, DIFP function will calculate the three differential currents as per the following equations:

$$Idiff\_L1 = I_A + \frac{U_{r2}}{U_{r1}} \times I_r + \frac{U_{r3}}{U_{r1}} \times I_u$$

$$Idiff\_L2 = I_B + \frac{U_{r2}}{U_{r1}} \times I_s + \frac{U_{r3}}{U_{r1}} \times I_v$$

$$Idiff\_L3 = I_C + \frac{U_{r2}}{U_{r1}} \times I_t + \frac{U_{r3}}{U_{r1}} \times I_w$$

Please note that in above equations, the three differential currents are related to HV transformer side (i.e. primary side). However it should be noted that set values for rated powers of the windings (Sr1, Sr2 & Sr3) under "Power Transformer Data" can influence on which side the differential currents will be transfered. The differential currents will be transferred to the side with maximum rated power, where maximum rated power is defined as maximum value of the three set values for Sr1, Sr2 & Sr3. If more than one winding has the rated power equal to the maximum rated power than order of preference will be primary winding, then secondary winding, then tertiary winding.

Protection Schemes for Railway Power Transformers

In addition to the features mentioned before it is as well possible to choose in RET 521 configuration tool in which reference direction connected current will be measured internally (i.e. + & - outputs available from AIM function blocks). This feature gives the user a possibility to measure the current in any direction he needs, as well as to sum or subtract two sets of three-phase currents by C3Cx summation function blocks. This feature enables user to perform current subtraction/summation in software, without any need for galvanic connections between different CT secondary circuits.

As mentioned before, RET 521 was in the first place design for protection of three phase power transformers. Therefore analogue quantities inside are very often treated in the three-phase manner (see previous figure for more details), and the same rules must be used for these special railway applications as well. Because of that it will be necessary to use some "zero current" (i.e. analogue input quantity with zero value) in order to build the artificial three-phase quantities inside the railway protection terminal. This zero current will be obtained from one RET 521 analogue CT input, which will not be connected (i.e. intentionally left unwired). The configuration parameters for this CT input shall be set in the following way:

CTprim=1A, CTsec=1A, InputCTTap=1A

In this way any noise from that CT input will be effectively suppressed.

In all configurations that will be shown in this document analogue CT input AIM1/Input04 will be used as zero current input.

Combination of all of these features gives the opportunity to use the RET 521 terminal as differential protection for special railway power transformers without any external auxiliary current transformers.

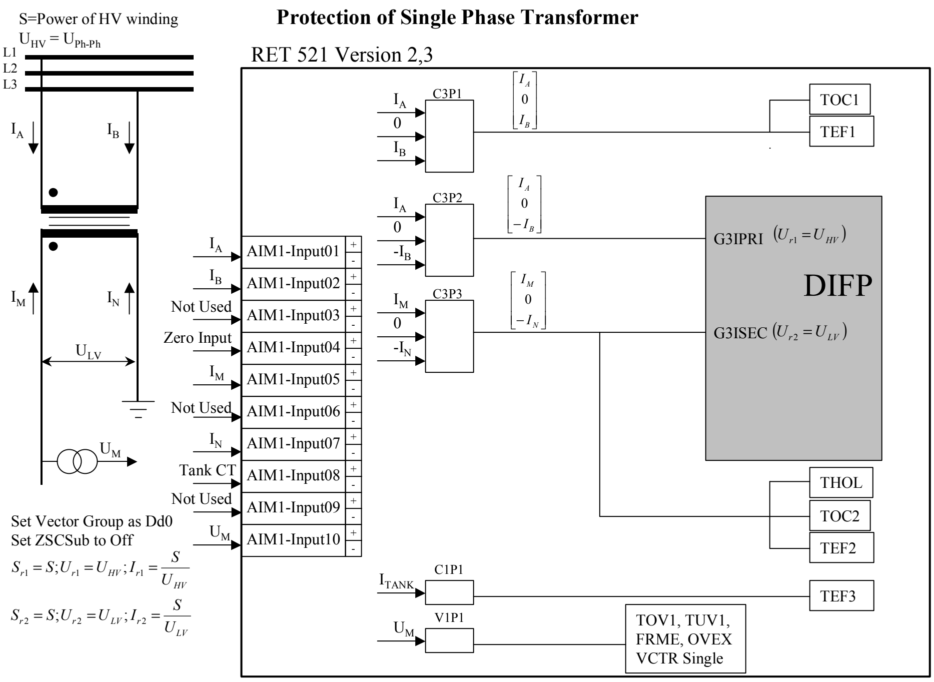
Typically required hardware in RET 521 for railway applications

All railway applications shown in this document can be realized with the identical RET 521 hardware configuration as listed bellow:

1 x AIM module (8I+2U) (eight current and two voltage inputs from the protected transformer)
1 x BIM module (16 binary inputs for connection of winding & oil contact thermometers, buchholz relay, external tripping devices, etc.)
1 x BOM module (24 contact outputs for trip commands, alarms, SCADA indications, etc.)
1 x MIM module (six, ±20mA input channels, which can be **optionally** used for on-load tap-changer position reading and/or oil & winding temperature measurement)
1 x SLM (SPA & LON communication module, which can be **optionally** used for terminal connection to the substation control system, substation monitoring system or remote interrogation of the terminal via public telephone network)

Protection Scheme for Single Phase Power Transformer

This type of transformer is commonly used in Europe in older types of railway installations. It is usually connected as shown in the following figure:



In the same time this figure shows the analogue quantities, which can be measured by RET 521. The Figure shows as well the analogue part of the configuration which need to be made in the CAP tool for this particular application. In this case the following functions can be included:

Function in RET	What-for the function is used in configuration
DIFP (2-winding)	Bias Differential function for the transformer (87T & 87H)
TOC1	HV overcurrent (50/51)
TEF1	HV earth-fault (50N/51N)
TOC2	LV overcurrent (50/51)
TEF2	LV winding earth-fault (50N/51N)
TEF3	Tank earth-fault protection (used in some countries i.e. France)
THOL	LV Thermal overload (49)
FRME	Frequency measurement
TOV1	LV Overvoltage (59)
TUV1	LV Undervoltage (27)
OVEX	Overexcitation (24)
VCTR (Single)	Voltage control for transformer with OLTC (90)
DRxx	Disturbance Recorder function for 10 analogue & 48 binary channels

Because the Dd0 vector group is used, the DIFP function will calculate the three differential currents as per the following equations:

$$Idiff\_L1 = I_A + \frac{U_{LV}}{U_{HV}} \times I_M$$

$$Idiff\_L2 = 0$$

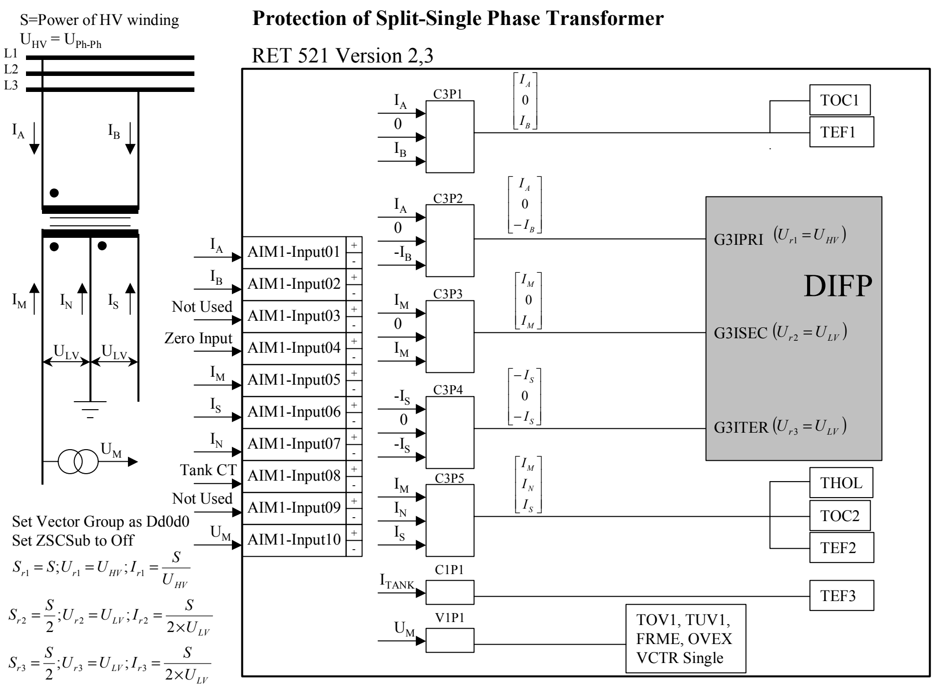
$$Idiff\_L3 = -I_B - \frac{U_{LV}}{U_{HV}} \times I_N$$

Therefore phase L1 & phase L3 will be used for differential protection, while phase L2 will measure zero current all the time (i.e. phase L2 in DIFP function will not be used). Please note that differential currents will be related to HV transformer side.

It should be observed that in practice very often only one HV CT & one LV CT are available. In that case it is even possible to protect two such railway power transformers with one RET 521 terminal. This opening gives possibility for more cost effective solutions.

Protection Scheme for Split-Single Phase Power Transformer

This type of transformer is commonly used in Europe for new railway installations (i.e. Italy & France). See the following figure for more information:



In the same time this figure shows the required analogue quantities which needs to be measured as well as the analogue part of the configuration which need to be made in the CAP tool for this particular application. In this case the following functions can be included:

Function in RET	What-for the function is used in configuration
DIFP (2-wndg)	Bias Differential function for the transformer (87T & 87H)
TOC1	HV overcurrent (50/51)
TEF1	HV earth-fault (50N/51N)
TOC2	LV overcurrent (50/51)
TEF2	LV winding earth-fault (50N/51N)
TEF3	Tank earth-fault protection (used in some countries i.e. France)
THOL	LV Thermal overload (49)
FRME	Frequency measurement
TOV1	LV Overvoltage (59)
TUV1	LV Undervoltage (27)
OVEX	Overexcitation (24)
VCTR	Automatic Voltage control (90)
DRxx	Disturbance Recorder function for 10 analogue & 48 binary channels

Because the Dd0d0 vector group is used, the DIFP function will calculate the three differential currents as per the following equations:

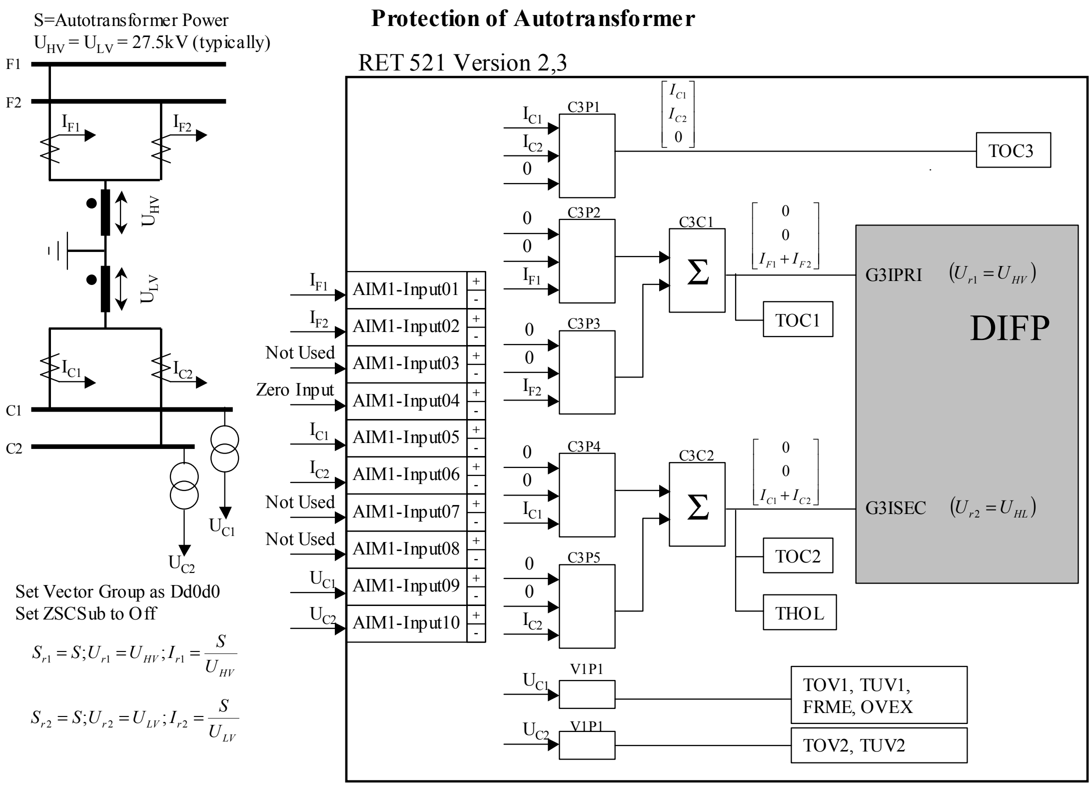
$$Idiff\_L1 = I_A + \frac{U_{LV}}{U_{HV}} \times I_M - \frac{U_{LV}}{U_{HV}} \times I_S$$
$$Idiff\_L2 = 0$$
$$Idiff\_L3 = -I_B + \frac{U_{LV}}{U_{HV}} \times I_M - \frac{U_{LV}}{U_{HV}} \times I_S$$

Therefore phase L1 & phase L3 will be used for differential protection, while phase L2 will measure zero current all the time (i.e. phase L2 in DIFP function will not be used). For this application differential currents will be related to HV transformer side.

Please note that, with some restriction, is as well possible to protect two of these transformers with one RET 521 terminal.

Protection Scheme for Autotransformer

Autotransformers are always used together with split-single phase transformer design (i.e.2x25kV railway supply system). Autotransformer is located in paralleling or traction station and is often shared between two railway tracks. Following figure shows typical installation layout:



In the same time this figure shows the required analogue quantities which needs to be measured as well as the analogue part of the configuration which need to be made in the CAP tool for this particular application. In this case the following functions are included:

Function in RET	What-for the function is used in configuration
DIFP (2-wndg)	Bias Differential function for the autotransformer (87T & 87H)
TOC1	Feeders side autotransformer overcurrent protection (50/51)
TOC2	Catenary side autotransformer overcurrent protection (50/51)
THOL	Autotransformer thermal overload protection (49)
TOC3	Catenary backup overcurrent protection
FRME	Frequency measurement
TOV1	Catenary 1 Overvoltage protection (59)
TUV1	Catenary 1 Undervoltage protection (27)
TOV2	Catenary 2 Overvoltage protection (59)
TUV2	Catenary 2 Undervoltage protection (27)
OVEX	Overexcitation (24)
DRxx	Disturbance Recorder function for 10 analogue & 48 binary channels

Because the Dd0d0 vector group is used, the DIFP function will calculate the three differential currents as per the following equations:

$$Idiff\_L1 = 0$$

$$Idiff\_L2 = 0$$

$$Idiff\_L3 = (I_{F1} + I_{F2}) + \frac{U_{LV}}{U_{HV}} \times (I_{C1} + I_{C2})$$

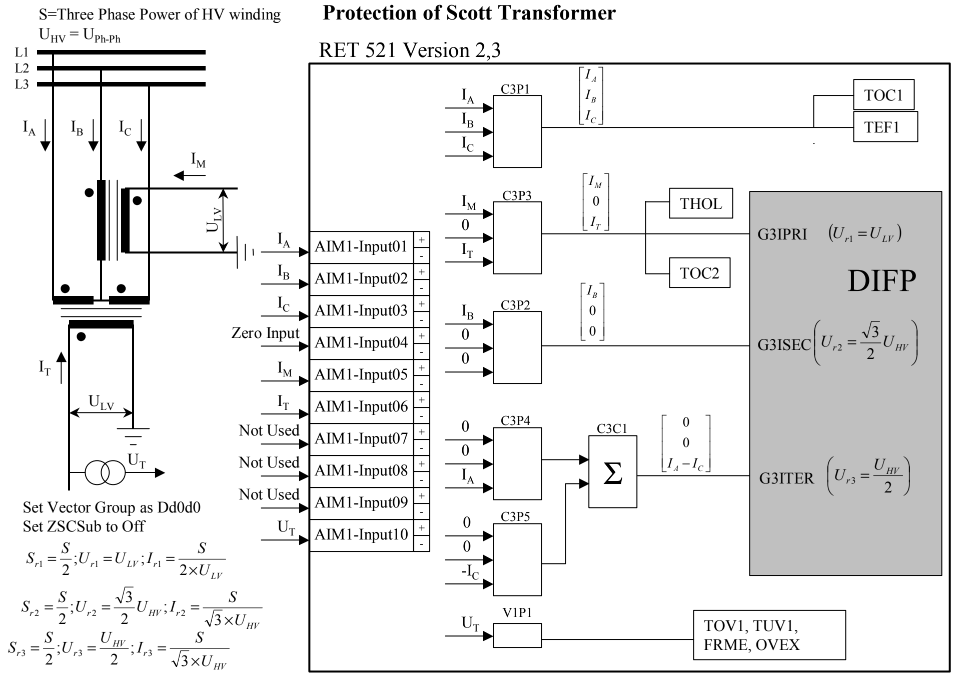
Therefore only phase L3 will be used for differential protection, while phases L1 & L2 will measure zero current all the time (i.e. L1 & L2 phases in DIFP function will not be used). For this application differential currents will be related to HV transformer side.

It should be noted that that backup overcurrent protection, for catenary is achieved by one RET function TOC3. Therefore the pickup and the time delay is the same for both phases. If required by the client, it is possible to use two earth-fault functions (i.e. TEF1 and TEF2) as independent overcurrent protections for each catenary. This will provide separate setting possibilities for each catenary as well as possibility for second harmonic restrain feature. It is as well possible to include autotransformer tank earth-fault protection if required.

Please note that for solutions where in the same paralleling station there is more than one autotransformer, it would be as well possible, with some restriction, to protect two or even three autotransformers with one RET 521 terminal.

Protection Scheme for Scott Power Transformer

This type of transformer is commonly used in Asia for railway installations (i.e. China & Korea). Its main feature is the ability to transfer three-phase power supply system to two-phase railway supply system. See the following figure for more information:



In the same time this figure shows the required analogue quantities which needs to be measured as well as the analogue part of the configuration which need to be made in the CAP tool for this particular application. In this case the following functions can be included:

Function in RET	What-for the function is used in configuration
DIFP (3-wndg)	Bias differential function for the transformer (87T & 87H)
TOC1	HV overcurrent (50/51)
TEF1	HV earth-fault (50N/51N)
TOC2	Overcurrent for 2-phase railway supply system (50/51)
THOL	Thermal overload for 2-phase railway supply system (49)
FRME	Frequency measurement
TOV1	LV overvoltage (59)
TUV1	LV Undervoltage (27)
OVEX	Overexcitation (24)
DRxx	Disturbance Recorder function for 10 analogue & 48 binary channels

It should be noted that only one phase voltage (i.e. U_T) of the 2-phase railway supply system is connected to RET 521. However it is possible to connect the other phase voltage (i.e. U_M) to the VT analogue input AIM1-Input09. If required another set of over/under voltage protection functions (i.e. TOV2 & TUV2) can be included to monitor/protect that winding voltage as well.

Because the Dd0d0 vector group is used, the DIFP function will calculate the three differential currents as per the following equations:

$$Idiff\_L1 = I_M + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times I_B + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times 0 = I_M + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times I_B$$

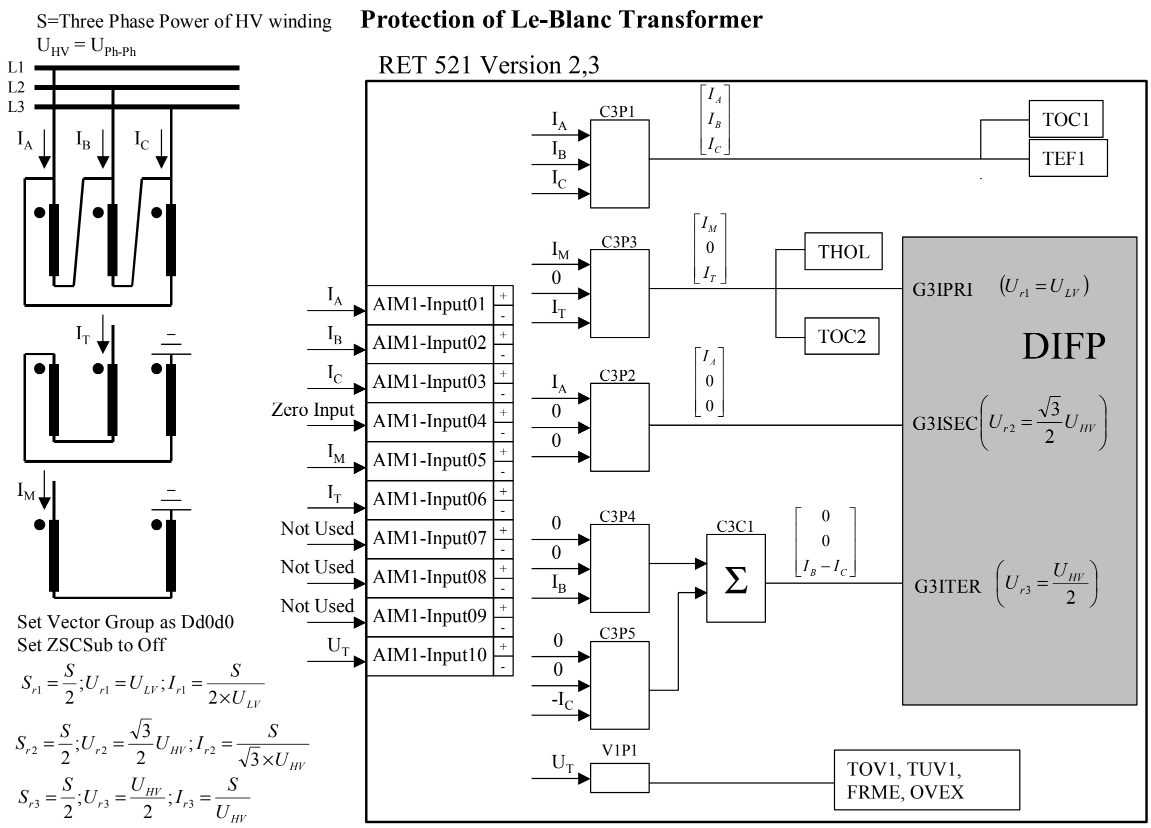
$$Idiff\_L2 = 0$$

$$Idiff\_L3 = I_T + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times 0 + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times (I_A - I_C) = I_T + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times (I_A - I_C)$$

Therefore phase L1 & phase L3 will be used for differential protection, while phase L2 will measure zero current all the time (i.e. phase L2 in DIFP function will not be used). Please note that differential currents will be related to 2-phase supply system side.
It should be noted that that overcurrent protection, for 2-phase railway supply system is achieved by one RET function TOC2. Therefore the pickup and the time delay is the same for both catenaries. If required by the client, it is possible to use two earth-fault functions (i.e. TEF2 and TEF3) as independent overcurrent protections for each catenary. This will provide separate setting possibilities for each catenary as well as possibility for second harmonic restrain feature.
It would be as well possible to include transformer tank earth-fault protection if required by the railway company.

Protection Scheme for Le-Blanc Power Transformer

This type of transformer is commonly used in Asia for railway installations (i.e. Taiwan). Its main feature is the ability to transfer three-phase supply system to two-phase railway supply system. See the following figure for more information:



$$S_{r1}=\frac{S}{2};U_{r1}=U_{LV};I_{r1}=\frac{S}{2\times U_{LV}}$$

$$S_{r2}=\frac{S}{2};U_{r2}=\frac{\sqrt{3}}{2}U_{HV};I_{r2}=\frac{S}{\sqrt{3}\times U_{HV}}$$

$$S_{r3}=\frac{S}{2};U_{r3}=\frac{U_{HV}}{2};I_{r3}=\frac{S}{U_{HV}}$$

In the same time this figure shows the required analogue quantities which needs to be measured as well as the analogue part of the configuration which need to be made in the CAP tool for this particular application. In this case the following functions can be included:

Function in RET	What-for the function is used in configuration
DIFP (3-wndg)	Bias differential function for the transformer (87T & 87H)
TOC1	HV overcurrent (50/51)
TEF1	HV earth-fault (50N/51N)
TOC2	Overcurrent for 2-phase railway supply system (50/51)
THOL	Thermal overload for 2-phase railway supply system (49)
FRME	Frequency measurement
TOV1	LV overvoltage (59)
TUV1	LV Undervoltage (27)
OVEX	Overexcitation (24)
DRxx	Disturbance Recorder function for 10 analogue & 48 binary channels

It should be noted that only one phase voltage (i.e. U_T) of the 2-phase railway supply system is connected to RET 521. However it is possible to connect the other phase voltage (i.e. U_M) to the VT analogue input AIM1-Input09. If required another set of over/under voltage protection functions (i.e. TOV2 & TUV2) can be included to monitor/protect that winding voltage as well.

Because the Dd0d0 vector group is used, the DIFP function will calculate the three differential currents as per the following equations

$$Idiff\_L1 = I_M + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times I_A + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times 0 = I_M + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times I_A$$

$$Idiff\_L2 = 0$$

$$Idiff\_L3 = I_T + \frac{\frac{\sqrt{3}}{2}U_{HV}}{U_{LV}} \times 0 + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times (I_B - I_C) = I_T + \frac{\frac{U_{HV}}{2}}{U_{LV}} \times (I_B - I_C)$$

Therefore phase L1 & phase L3 will be used for differential protection, while phase L2 will measure zero current all the time (i.e. phase L2 in DIFP function will not be used). Please note that differential currents will be related to 2-phase supply system side.

It should be noted that that overcurrent protection, for 2-phase railway supply system is achieved by one RET function TOC2. Therefore the pickup and the time delay is the same for both phases. If required by the client, it is possible to use earth-fault functions TEF2 and TEF3 as overcurrent protections for I_T & I_M respectively. This will provide separate settings for two phases as well as possibility for second harmonic restrain feature.

It would be as well possible to include transformer tank earth-fault protection if required by the railway company.

Conclusion

Typical protection schemes with RET 521 terminal for most common types of railway power transformers has been presented. However it should be noted that these are only typical schemes. If you have any other requirements for protection of electrical railway supply system, please do contact your local ABB representative in order to make tailor-made solution in accordance with your demands.

References:

1. Bin-Kwie Chen and Bing-Song Guo, "Three Phase Models of Specially Connected Transformers", IEEE, Transaction on Power Delivery, Vol. 11. No 1, January 1996

2. Modolf Stien, “Differential och impedansreläer för Scott-transformatorer”, ASEA RELAYS, 1988-04-26

3. Kwang-Chang Lu and Nanming Chen, “A Two-Relay Differential Protective Scheme for Le-Blanc Transformers”, IEEE, Transaction on Power Delivery, Vol. 14. No 3, July 1999

4. Jin-Maun Ho and Tsung-Ling Tsou, “The effect analysis and Simulation Test of Harmonics on Differential Protection of Scott Transformers”, IEEE Porto Power Tech Conference, Portugal 2001