For big generator-transformer units overall differential protection is often required. This document will provide a practical example how to engineer such protection scheme with RET670 or REG670. The single line diagram of the application used throughout this document is given in Figure 1. In this particular case two auxiliary power transformers are present in the station. Note that all relevant plant data necessary for the protection scheme engineering are also given in this figure.

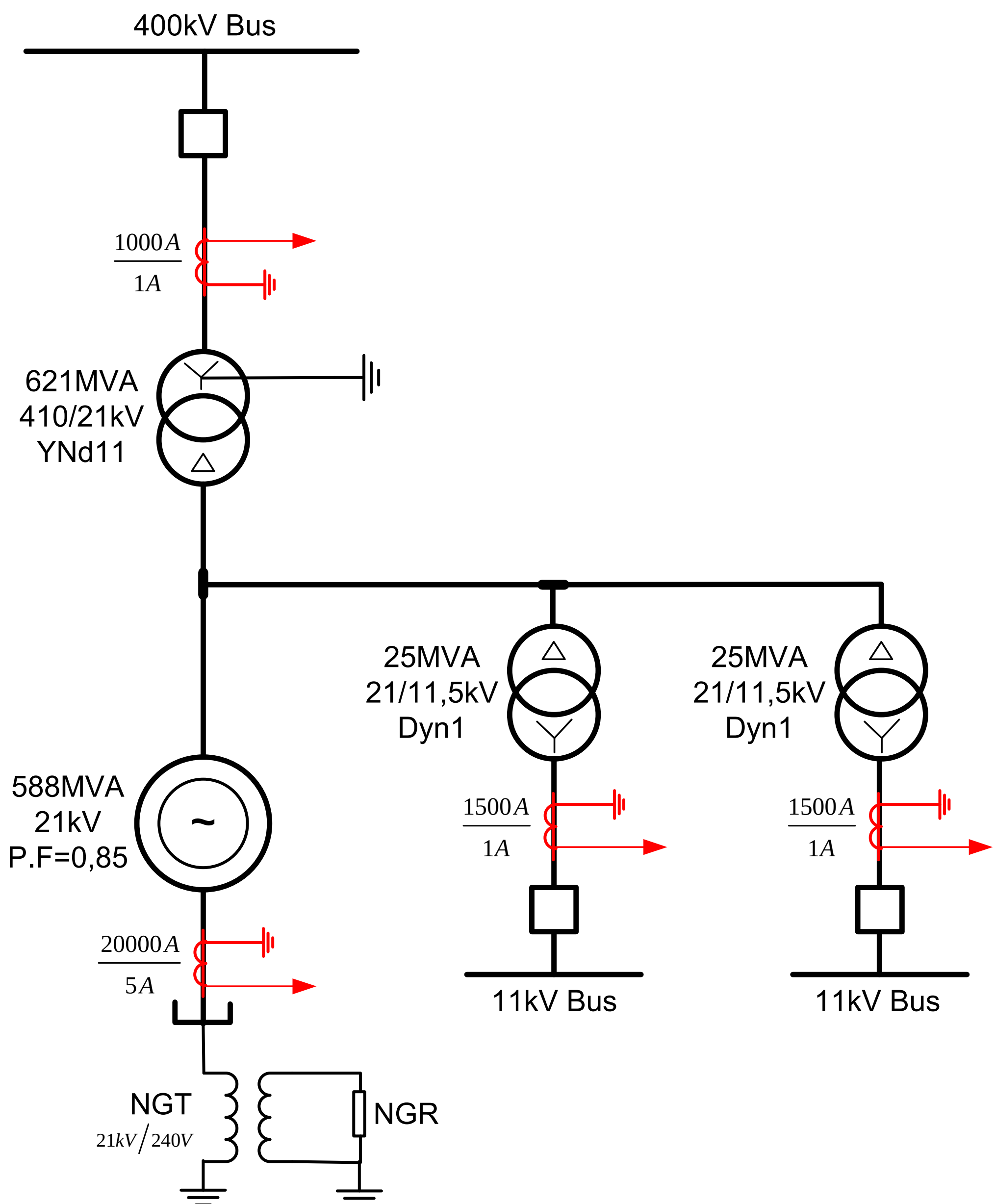

Figure 1: Single line diagram of the application used example

Because three different voltage levels are involved (i.e. 400kV, 21kV & 11kV) three winding transformer differential protection function T3WPDIF within RET670/REG670 shall be used.

First of all it should be understood that the maximum power among all objects within the protected zone shall be taken as a base in case of the overall differential protection. In this application this is 621MVA (i.e. maximum value among 621MVA, 588MVA and 25MVA). This base power will than represent the base (i.e. 100%) for this application (e.g. for example the operating characteristic of the differential protection for this application will be given in respect to this power value). This principle of the maximum power is explained in more details in references [1], [2] & [3].

For this particular application this maximum power corresponds to the following base currents on three different voltage levels connected to the relay:

- At 400kV: $\frac{621MVA}{\sqrt{3}\cdot 410kV} = 874A$

  This corresponds to 0,874A on the secondary side of 1000/1 CT.
- At 21kV: $\frac{621MVA}{\sqrt{3}\cdot 21kV} = 17073A$

  This corresponds to 4,268A on the secondary side of 20000/5 CT.
- At 11kV: $\frac{621MVA}{\sqrt{3}\cdot 11.5kV} = 31177A$

  This corresponds to 20,785A on the secondary side of 1500/1 CT.

Note that for the above base current calculations the transformer rating plate voltages shall be used (i.e. not the rated network voltage). For example the 410kV value is used instead of 400kV on the HV side of the step-up transformer.

Above currents will be the base current for each side. If overall differential protection is set to 20% the function will pickup when 20% of the base secondary current is injected as a symmetrical three-phase current from each respective side (see Section 4 of this document for more details about testing).

Two different protection solutions will be given depending on which winding of the step up transformer will be considered as the main (i.e. primary or first) winding.

1 HV side of the step-up transformer is considered as main winding

This is the most natural way to connect the overall differential relay. In this case 400kV CT is connected as winding 1, 21kV CT from the generator neutral point as winding two and two 11kV CTs as winding 3. This practically means that currents to the T3WPDIF function block shall be connected as shown in Table 1.

Table 1: CT connection s towards T3WPDIF function block

CT	Inputs into T3WPDIF function block
1000/1 from 410kV side	I3PW1CT1
20000/5 from 21kV side	I3PW2CT1
1500/1 from 11,5kV side	I3PW3CT1 & I3PW3CT2

The principle CT connections are shown in Figure 2.

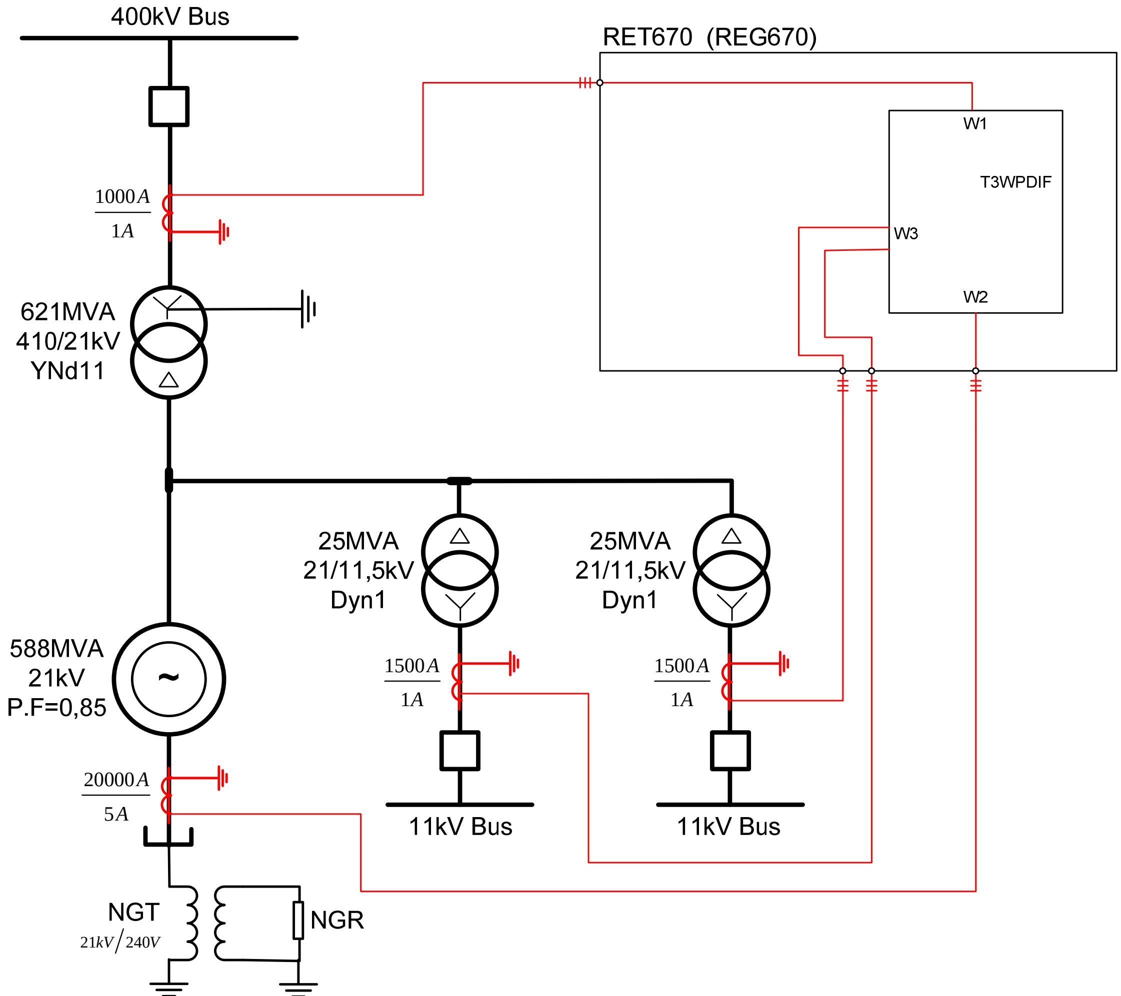

Figure 2: Principle CT connections for the first solution

The individual winding compensation settings shall be entered in the same sequence as CT connections. The correct settings for this set-up are shown in Figure 3.Note that for this solution the compensation settings simply follow the power transformer rating plate data.

Note that for this solution the service values (i.e. bias and differential currents) from the 87O function will be given in primary amperes on the 400kV side (i.e. winding 1 side).

T3WPDIF(IdT): 1		
RatedVoltageW1	410,00	kV
RatedVoltageW2	21,00	kV
RatedVoltageW3	11,50	kV
RatedCurrentW1	874	A
RatedCurrentW2	17073	A
RatedCurrentW3	31177	A
ConnectTypeW1	WYE (Y)	
ConnectTypeW2	Delta (D)	
ConnectTypeW3	**WYE (Y)**	
ClockNumberW2	**11 [30 deg lead]**	
ClockNumberW3	**0 [0 deg]**	
ZSCurrSubtrW1	On	
ZSCurrSubtrW2	Off	
ZSCurrSubtrW3	**On**	
TconfigForW1	No	
CT1RatingW1	**1000**	A
CT2RatingW1	**1000**	A
TconfigForW2	No	
CT1RatingW2	**20000**	A
CT2RatingW2	**20000**	A
TconfigForW3	**Yes**	
CT1RatingW3	**1500**	A
CT2RatingW3	**1500**	A
LocationOLTC1	Not Used	

Figure 3: Necessary compensation settings for 87O function (Solution 1)

2 Generator neutral point side is considered as main winding

This is the other way to connect the differential scheme. In this case 21kV CT from the generator neutral point is connected as winding 1, 400kV CT as winding two and two 11kV CTs as winding 3. Note that for the second solution CT connections towards the differential function's winding 1 and winding 2 shall be swopped in ACT in respect to the first solution. At the same time the physical CT wiring shall remain the same as for the first solution.

Table 2: CT connection s towards T3WPDIF function block

CT	Inputs into T3WPDIF function block
20000/5 from 21kV side	I3PW1CT1 (swop connections in ACT from solution 1)
1000/1 from 410kV side	I3PW2CT1 (swop connections in ACT from solution 1)
1500/1 from 11,5kV side	I3PW3CT1 & I3PW3CT2

The principle CT connections are shown in Figure 4. Note the current swop in the ACT in comparison with the first solution!

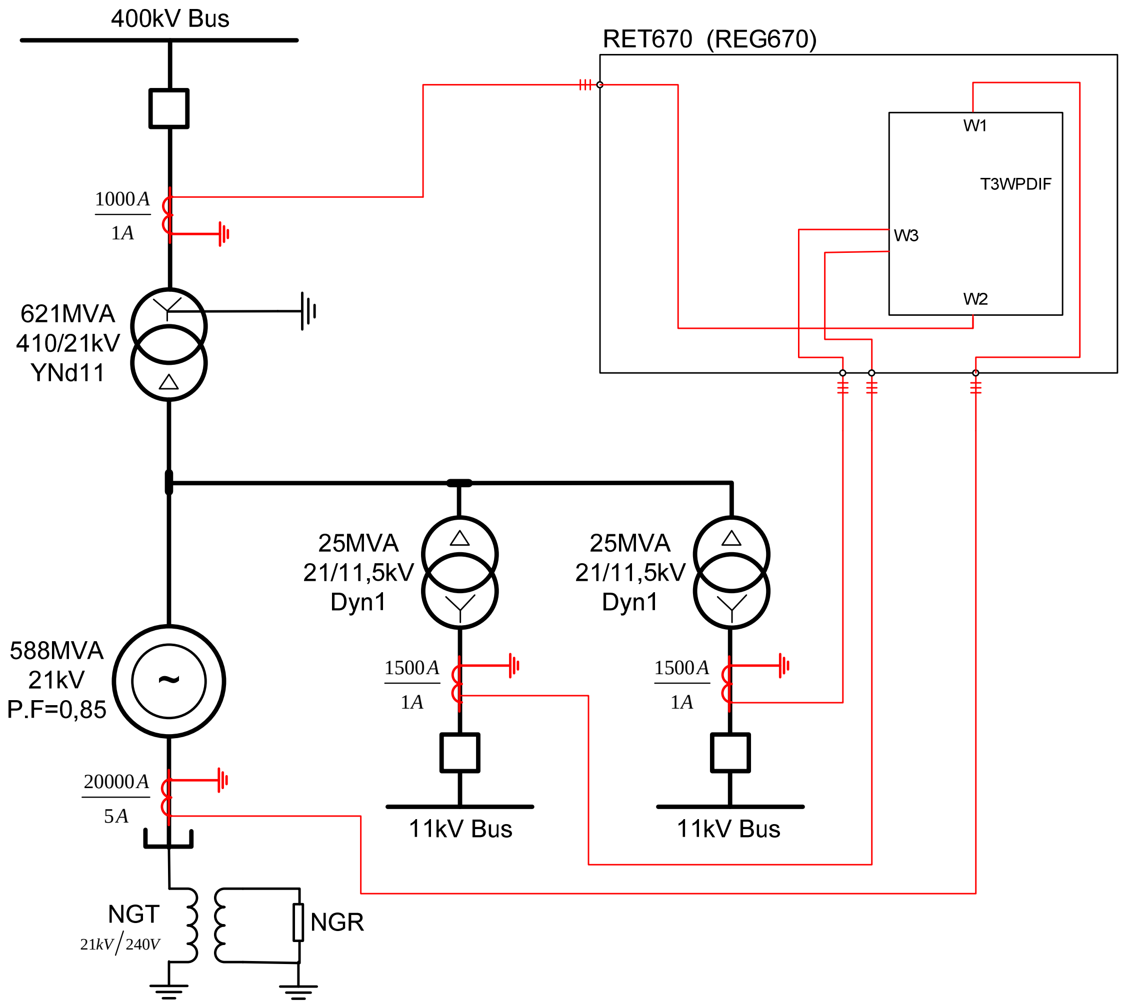

Figure 4: Principle CT connections for the second solution

The individual winding compensation settings shall be again entered in the same sequence as CT connections. The correct settings for the second solution are shown in Figure 5. Note that for this solution the compensation settings do NOT follow the power transformer rating plate data. Especially the vector group has to be entered in a little bit special way. Namely the secondary delta winding, which is now taken as the first winding, shall be position to 12 o'clock and other two windings clock numbers shall be entered in respect to that one. Correct clock numbers for such scheme set-up are given in Figure 5.

Note that for this solution the service values (i.e. bias and differential currents) from the 87O function will be given in primary amperes on the 21kV side (i.e. winding 1 side).

T3WPDIF(IdT): 1		
RatedVoltageW1	21,00	kV
RatedVoltageW2	410,00	kV
RatedVoltageW3	11,50	kV
RatedCurrentW1	17073	A
RatedCurrentW2	874	A
RatedCurrentW3	31177	A
ConnectTypeW1	Delta (D)	
ConnectTypeW2	WYE (Y)	
ConnectTypeW3	WYE (Y)	
ClockNumberW2	1 [30 deg lag]	
ClockNumberW3	1 [30 deg lag]	
ZSCurrSubtrW1	Off	
ZSCurrSubtrW2	On	
ZSCurrSubtrW3	On	
TconfigForW1	No	
CT1RatingW1	20000	A
CT2RatingW1	20000	A
TconfigForW2	No	
CT1RatingW2	1000	A
CT2RatingW2	1000	A
TconfigForW3	Yes	
CT1RatingW3	1500	A
CT2RatingW3	1500	A
LocationOLTC1	Not Used	

Figure 5: Necessary compensation settings for 87O function (Solution 2)

3 Setting of the differential relay characteristic

Irrespective which one of the two possible solutions is used differential protection characteristic settings can be set in the same way. Because this power transformer does not have the on-load tap-changer the minimum pickup can be set to 20%. All other settings for the operating characteristic can be left to the default values. Because the differential protection zone contains more than one power transformer it is recommended to set pickup value for the negative sequence part of the algorithm to the maximum value. All settings are shown in Figure 6.

Setting Group1				
Operation	On			
SOTFMode	On			
IDiffAlarm	**0,05**	IB	0,05	1,00
tAlarmDelay	10,000	s	0,000	60,000
IdMin	**0,20**	IB	0,05	0,60
EndSection1	1,25	IB	0,20	1,50
EndSection2	3,00	IB	1,00	10,00
SlopeSection2	40,0	%	10,0	50,0
SlopeSection3	80,0	%	30,0	100,0
IdUnre	10,00	IB	1,00	50,00
I2/I1Ratio	15,0	%	5,0	100,0
I5/I1Ratio	25,0	%	5,0	100,0
CrossBlockEn	On			
NegSeqDiffEn	On			
IMinNegSeq	**0,20**	IB	0,02	0,20
NegSeqROA	60,0	Deg	30,0	120,0
OpenCTEnable	Off			
tOCTAlarmDelay	3,000	s	0,100	10,000
tOCTResetDelay	0,250	s	0,100	10,000
tOCTUnrstDelay	10,00	s	0,10	6000,00

Figure 6: Settings for 87O operating characteristic

4 Testing issue

Regardless which one of the two possible solutions is used testing of the 87O protection scheme and protection pickup values will be the same. Because the minimum pickup is set to 20% function will pickup when 20% of base secondary current is injected on any of the three sides. These three-phase pickup values in primary and secondary amperes for this application are given in Figure 7 under "Ideal 3Ph Fault" values.

Single phase pickup will be slightly different. Due to "software interposing CTs" used inside the algorithm [3], [4] pickup for single phase injection will be bigger for a factor than the pickup for 3Ph fault [4]. For two star connected windings (i.e. 400kV and 11,5kV sides) this factor has value of 1, 5. For delta connected winding (i.e. 21kV side) this factor has value of 1,732 (i.e. sqrt(3)) [4]. These single-phase pickup values in primary and secondary amperes are given in Figure 7 under "Ideal 1Ph Fault" values.

							Primary Pickup	Secondary Pickup	
	Ur [kV]	Connection	CT Primary	CT Secondary	Idmin [%]	ZSCurrSubtr	Ideal 3Ph Fault		
W1	410,00 kV	Star	1000 A	1 A		On	174,8 A	0,175 A	W1
W2	21,00 kV	Delta	20000 A	5 A	20	Off	3412,8 A	0,853 A	W2
W3	11,50 kV	Star	1500 A	1 A		On	6232,0 A	4,155 A	W3
							Ideal 1Ph Fault		
							262,2 A	0,262 A	W1
							5910,9 A	1,478 A	W2
							9348,0 A	6,232 A	W3

Figure 7: Calculation of pickup value for the testing of the overall differential protection

Testing of the 87O scheme stability and operation shall be performed as explained in reference [4].

5 References

[1] ABB RADSB User's Guide, Document ID: 1MRK 504 002-UEN

[2] BBC Publication "Instruction for Planning Differential Protection Schemes", Document ID: CH-ES 53-10 E, BBC January 1980

[3] Z. Gajić, "Differential protection methodology for arbitrary three-phase power transformers", IET, DPSP 2008 Conference, Glasgow-UK, 2008

[4] Z. Gajić, F. Mekić, "Easy and Intuitive Method for Testing Transformer Differential Relays", 62nd Annual Georgia Tech Protective Relaying Conference, May 2008, Atlanta USA

REVISION

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