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NIZHNY NOVGOROD STATE TECHNICAL UNIVERSITY N.A. R.E. ALEKSEEV

Study Committee D1

Materials and Emerging Test Techniques

Paper D1-PS3-11162

The Use of Machine Learning and Artificial Neural Networks to Recognition of Turning Faults in Power Transformers

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Motivation

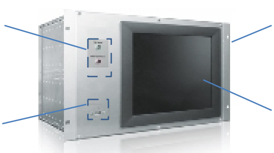
- Low efficiency of the relay protection of the power transformer (70% of correct operations).
- Low sensitivity (recognition) of turning faults in transformers.
- Improving the relay protection systems of a power transformer using an artificial neural network.

Consequences of turning faults in power transformers

Object of investigation

- Development of protection for recognition of turn short circuits in a power transformer using artificial neural network (ANN) algorithms.

Relay diagnostic device layout



Terminal operation indication

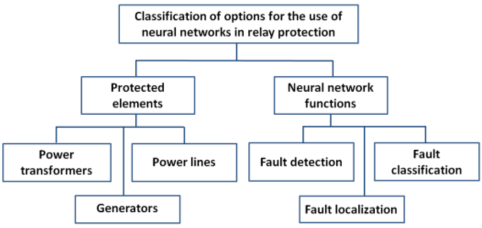
USB port

Chassis 6U rack 19''

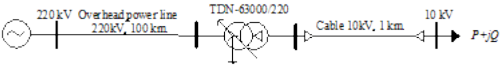
12'' LCD display

Method/Approach

- Machine learning, artificial neural network (ANN), neural network algorithms.

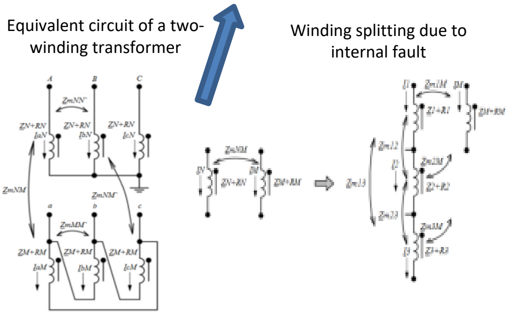


Mathematical model for the study of turning short circuits in a power transformer



Equivalent circuit of a two-winding transformer

Winding splitting due to internal fault



Exploration Modes

Normal operation

Turning short circuit in windings

Network parameter ranges for generating statistics

Parameter		Designation	Change range
System voltage		*Es*	[0,95…1,05] p.u.
System positive sequence resistance module		*Zs*	[10…42] Ohm
System positive sequence drag angle		*deltaZs*	[80…90] deg
Load value	Load active power	*P*	[10…40] kW
	tgϕ	tg*PQ*	[0,2…0,4] p.u.
For turning faults:	Change in the number of closed winding turns	*L*	[0,02…1] %
	Voltage fault occurrence	-	220; 10,5 kV
	Fault initiation phase	-	A, B, C

ANN in the protection algorithm

- **First case** - for immediate decision making (as a trigger)
- **Second case -** for calculation of coefficients of multiparameter protection

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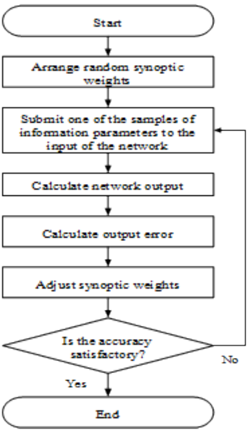
Neural network training

Algorithm for training a neural network using the backpropagation method



Training sample input

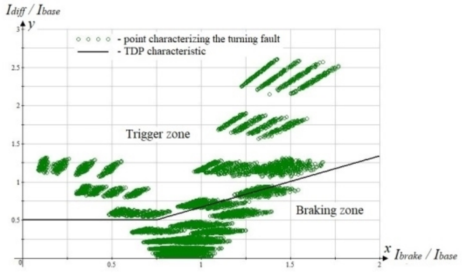
Mode	TF	NM	NM	NM	NM	TF	NM	…
Number	1	2	3	4	5	6	7	…
Ia1	0,683	0,662	0,642	0,704	0,618	0,564	0,61	…
Ib1	0,711	0,662	0,642	0,704	0,618	0,768	0,61	…
Ic1	0,536	0,662	0,642	0,704	0,618	0,755	0,61	…
…	…	…	…	…	…	…	…	…
Ia2	0,644	0,713	0,691	0,757	0,666	0,71	0,657	…
…	…	…	…	…	…	…	…	…

Training sample output

Mode	TF	NM	NM	NM	NM	TF	NM	…
Number	1	2	3	4	5	6	7	…
Value	1	0	0	0	0	1	0	…

TF - turning faults; NM - normal mode

Simulation results of turning faults and functioning of the differential protection of the transformer (TDP) (phase A)

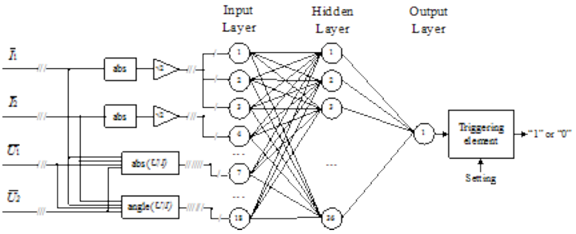


Large array of points, characteristic of turning faults, lies in the zone of failure of the differential protection. Thus, TDP is not able to recognize all cases of turning short circuits from the test sample (not more than 45%). It is an unsatisfactory result.

First case

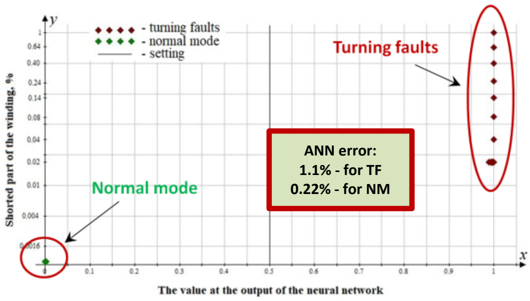
Neural network as a trigger for protection

Variant for organizing relay protection of a transformer with the direct use of ANN



Discussion

The results of modeling of turning faults and the functioning of the triggering element based on ANN



- In this variant, the neural network ensures the adoption of discrete decisions "0" or "1", respectively, in the normal mode and with a turning fault.
- The test was carried out on a limited test set of modes. When applying input data to the ANN that were not included in the original training (test) sample, there may be cases of making wrong decisions.

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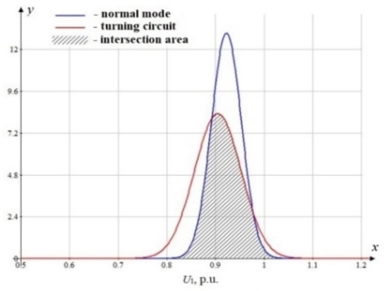
Second case

Neural network for calculation of coefficients of multiparameter protection

- Using the ANN, a generalized feature (**μ**) is formed, designed to recognize short circuits.
- To form a generalized feature (**μ**) , information features (**xi**) (current, voltage, phase resistance, etc.) from the training sample are used.
- In this case, the ANN is used as a tool to calculate the weight coefficients (**wi**) for each feature xi.
- The decision algorithm is similar to that traditionally used in relay protection - comparison with the setting.

Determining the feature weighting coefficient

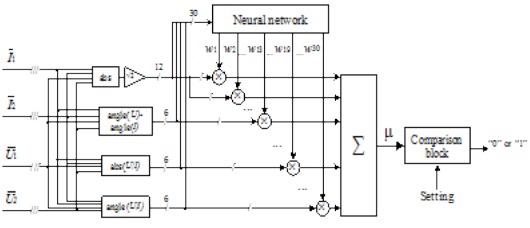


Training sample output

Mode	TF	NM	NM	NM	NM	TF	NM	...
Number	1	2	3	4	5	6	7	...
w_1	1,353	0	0	0	0	1,353	0	...
w_2	3,765	0	0	0	0	3,765	0	...
w_3	1,679	0	0	0	0	1,679	0	...
w_i	...	...	...	...	...	...	...	...

TF - turning faults; NM - normal mode

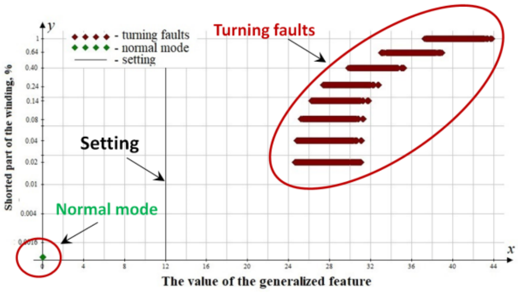
Variant of organizing the relay protection of a transformer using a generalized feature



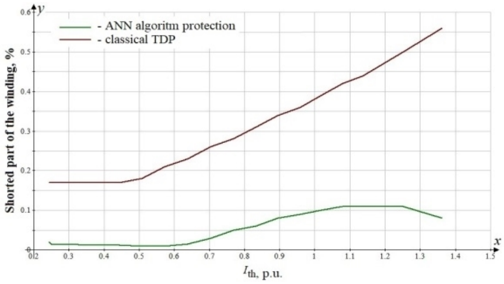
xi – informative feature
wi – informative feature weight coefficient
μ – generalized feature

Discussion

The results of testing the relay protection of the transformer using the generalized feature of triggering



Protection Sensitivity Comparison. Dependencies characterizing the sensitivity of the transformer protections on the value of the through current



Conclusion

- Of the two cases for the proposed and studied transformer protection based on ANN, the case using a generalized feature is preferable and easy to implement.
- The results of the simulation showed that the transformer protection developed with the use of the ANN has a higher (more than 5 times) sensitivity compared to the classical TDP.
- Implementation of the developed neural network algorithms into the logical part of the relay protection device will make it possible to protect the power transformer more effectively and to recognize turning faults at the early stages of fault development.
- In the future, it is planned to study the functioning of digital models of neural network algorithms and compare them with the operation of a real terminal with traditional TDP on the RTDS NovaCor with conducting semi-natural experiments.

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