LARSEN & TOUBRO LIMITED

TRANSFORMER PROTECTION
PRACTICES & CURRENT TRENDS

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Transformer Protection- Existing practices and new trends

1.0 **General:** Transformers are the most important main equipment in any Power Transmission & Distribution network. The performance of the transformers depends upon how well they are maintained & protected against all possible fault conditions that can arise in the installation, in the network and the ambient environment.

The following sections describe the role of Protective relays in assuring the satisfactory performance of transformers both from fault clearance and maintenance point of views.

2.0 **Types of Transformers** : Transformers in a power system can be divided into three major categories:

Small size transformers, less than 1 MVA size. These are used mostly at the distribution end with 11kV/415V ratings.

Medium size transformers (1 MVA to 10 MVA) : these are used in secondary sub-stations of state utilities and plant incomers. Voltage ratings on the primary side can vary from 220 kV to 33 kV. The secondary side voltages can vary from 33 kV to 3.3 kV.

Large size transformers (above 10MVA): These Are used in primary substations of state utilities, incomers of large industries (like cement plants, fertilizer plants etc). The primary voltages can be either 400 kV or 220 kV. Secondary voltages can vary from 110 kV to 33 kV. Many of these may have three windings.

Apart from the above one may come across special types of transformers like rectifier transformers, reactors etc.

Management of sub-stations with large transformers, from a remote location is becoming a major activity. This function is now being integrated into the protection system of transformers.

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3.0 **Protection philosophy** : The type and extent of protection for transformers depends upon :

a) the size and importance of duty performed
b) the location of the transformer in the power system

Transformers have to be protected both for external faults (faults occurring outside the terminals of the transformer) as well as the Internal faults (faults occurring within the transformer).

Normal over current + Earth fault relays are adequate for protection against external faults. Special relays like differential and REF relays are required for protection against internal faults. Sections 4,5 &6 explain the types of faults, method of protections for each fault, recommended types of relays etc.

Apart from fault conditions, which are severe abnormalities in electrical parameters, there are three major killers of transformers in the present day transmission system. These are :

a) **Over load conditions** : These produce excessive heat which causes rise in operation temperature. Every 10 degree rise in temperature (beyond the withstand limit specified) results in 50% reduction in life of transformer insulation.

b) **Single phasing conditions** : There are increasing incidences of single phasing in transformers . The main reasons are poor maintenance of transmission lines and circuit breakers.

c) **Unbalanced loads** : Any unbalance in the three phase currents of a transformer will cause over heating , even if the currents are within rated values. Certain level of unbalance can be tolerated by transformer design – however we have to worry about unbalances more than 20%. Large unbalances can cause neutral shift , which may be harmful to end users. If excessive neutral shift takes place, there can be flashover in sub-station.

These three conditions are on the rise in many substations – including some of the industrial plants. Necessary care has to be incorporated in the protection systems to handle these situations.

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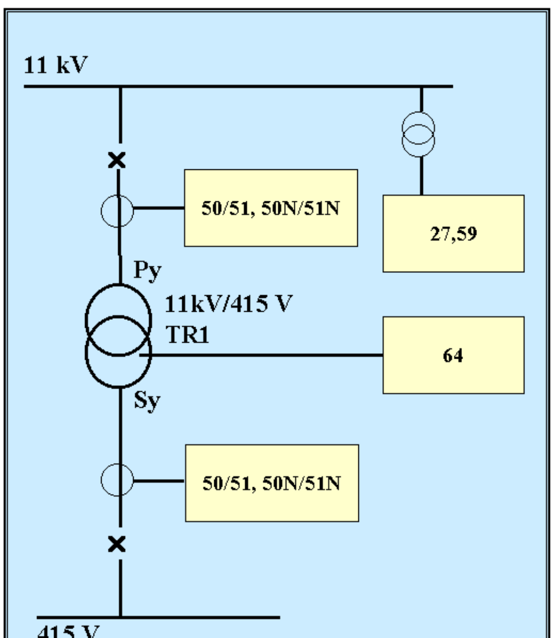
4.0 <u>Protection of small transformers (Less than 1MVA) :</u>

The following figures show the SLD and the list of protections. Bare minimum protections are envisaged – since economy of protections is the major factor in deciding the extent of protection.

a) **<u>Low set Over Current Protection (51)</u>** : Used to protect the transformer from over currents in Py and Sy side. Pick levels are normally around 140% to 150%. Normal Inverse IDMT characteristics are followed for trip time.

b) **<u>Highset Over current Protection (50)</u>** : Used to protect from high level fault currents of the order of 300% and above. Always instantaneous trip.



Protection of Small size Transformers (Less than 1 MVA)

<u>Primary Side :</u>

50	**Over Current (Instantaneous)**
50N	**Earth Fault (Instantaneous)**
51	**Over Current (IDMT)**
51N	**Earth Fault (IDMT)**
27	**Under Voltage**
59	**Over Voltage**

<u>Secondary Side :</u>

50	**Over Current (Instantaneous)**
50N	**Earth Fault (Instantaneous)**
51	**Over Current (IDMT)**
51N	**Earth Fault (IDMT)**
64	**Restricted Earth Fault**

c) **<u>Under Voltage protection (27)</u>** : This is a bus level protection – pick up levels are normally 85% and below.

d) **Over voltage protection (59)** : This is a bus level protection – pick up levels are around 110%.

e) **Restricted Earth fault protection (64)** : Normally provide on the star connected side – for protection transformer from internal faults.

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5.0 Protection of medium size transformers (1 to 10 MVA):

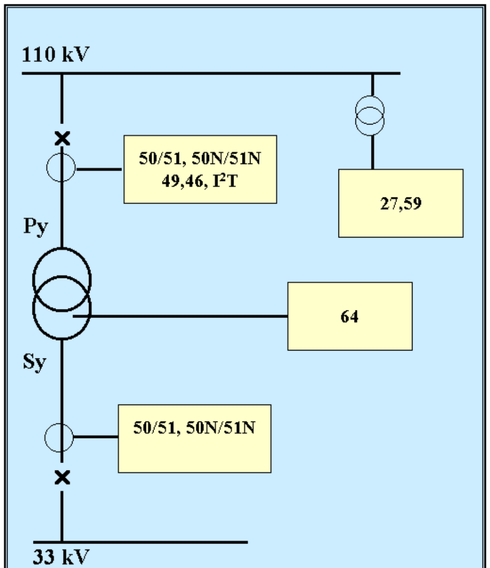
Please refer the SLD and the list of protections, shown below:

Since the transformer is handling a higher power and it is in a key location like the incomer of a substation or an industry, following additional protections are advised.

a) Thermal Overload protection (49) : Let us consider a case where a normal over current relay with pick up level of 140% is used. It should be noted that the transformer is in the over load region between 105% to 140%. If the load is around 135%, the O/C relay will not protect – but the transformer will get hot and loose its life. Thermal overload protection will help in this case.

It is also beneficial to monitor the overload conditions in the winding and the core separately. The copper portion will get hot faster – for a given overload current, trip time will have to be faster than that for iron core.

b) Current Unbalance protection (46) : This will protect transformers against heavy unbalances. In case of unbalance currents, the negative sequence component will increase – resulting in over heating of transformers. It is advisable to have two levels of unbalance protection – one for alarm and other for trip.



Protection of Medium size Transformers (1 MVA to 10 MVA)

Primary Side :

50	**Over current (Instantaneous)**
51	**Over Current (IDMT)**
50N	**Earth Fault (Instantaneous)**
51N	**Earth Fault (IDMT)**
49	**Thermal Over Load**
46	**Current Unbalance**
I^2T	**Inrush energy**
27	**Under Voltage**
59	**Over Voltage**

Secondary Side:

50	**Over current (Instantaneous)**
51	**Over Current (IDMT)**
50N	**Earth Fault (Instantaneous)**
51N	**Earth Fault (IDMT)**
64	**Restricted Earth Fault**

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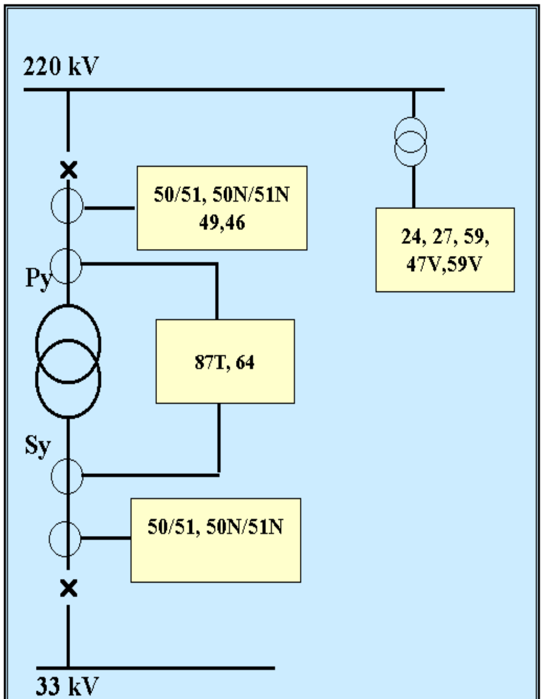
d) I^2T Protection : This protection is very useful for rectifier transformers – where the currents will be fluctuating . In this case the energy dissipated for given over current condition is set as trip limit. If this energy level is exceeded, the transformer is tripped earlier than the IDMT over current trip for the same value.

6.0 **Protection of Large size transformers (above 10 MVA)** : What we are talking about here are very large bulk power handling transformers where the criticalities are very high. Consequently more protections , than those listed in section 5 above, are envisaged.

The extra protections are in the form of differential and over fluxing protections which are mainly internal faults.



Protection of Large size Transformers (Above 10 MVA)

Primary Side :

50	**Over current (Instantaneous)**
51	**Over Current (IDMT)**
50N	**Earth Fault (Instantaneous)**
51N	**Earth Fault (IDMT)**
49	**Thermal Over Load**
46	**Current Unbalance**
I^2T	**Inrush energy**
27	**Under Voltage**
59	**Over Voltage**
24	**Over Fluxing**
47V	**Voltage unbalance**

Secondary Side:

50	**Over current (Instantaneous)**
51	**Over Current (IDMT)**
50N	**Earth Fault (Instantaneous)**
51N	**Earth Fault (IDMT)**
64	**Restricted Earth Fault**

Combined protection:

87	**Differential Protection**

a) **Differential Protection (87)** : This is one of the major protections for large transformers. This protects the transformers whenever there is an internal fault . As shown in the SLD, this protection needs two additional sets of CTs, which are perfectly matched and have adequate knee point voltage to drive a relay measuring circuit. It should be noted that:

- a differential relay should trip only for an internal fault
- a differential relay should never trip for an external/through fault.

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For this reason a percentage biased relay, with dual slope facility will be the best choice. This will have a very good through fault stability.

It may so happen that a differential relay can trip whenever the transformer is switched on. This is due to the magnetizing inrush current flowing only in primary side of the transformer. To avoid this , the relay should have a second harmonic restraint facility. Similarly a 5^{th} harmonic restraint facility in the relay will help avoiding a differential trip during temporary over fluxing conditions.

b) **Voltage unbalance protection (47V)** : Voltage unbalance in large transformers are good indication of a grid disturbance. Can be used as an alarm .

c) **Over fluxing protection (24)** : This is to monitor the flux levels inside the large transformer. If the per unit ratio of V/Hz goes beyond a value 1.05, the transformer will go into an over fluxing condition – this will cause over heating even when the currents are within limits. Hence the need to monitor separately.

7.0 **Monitoring of E/F in ungrounded transformers** : In case of transformers, predominantly medium size, there can be installations where the neutral is grounded through an impedance or high resistance. In this when an earth fault occurs, normal E/F relays will not work – since the required relay operating current will not flow in the ground path. Consequently, a different method has to be adopted - monitoring the zero sequence voltage . The zero sequence voltage is a good indication of a neutral shift, which happens when there is an earth fault.

There are two schemes for monitoring the neutral shift –

a) use an open delta transformer + a low cost voltage relay. In this case the open delta transformer may become expensive.
b) use normal star connected bus PT – but with a relay which calculates zero sequence voltage by numerical methods.

8.0 **Power Management concept :** One of the main concerns of power transmission is the poor power factor conditions at the HT level. Many substations are resorting to adding HT capacitor banks for improving the pF – particularly at 33kV and 11 kV levels. Special relays like Capacitor bank protection relays, Reactive power measuring relays, Voltage & PF monitoring relays will be required here.

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9.0 **Grid Islanding & Load shedding :** This requirement is very important to keep power transmission stable, within a specified area where there is a reasonable power generation available, when there is a large scale grid disturbance. In this case the entire grid , under disturbed conditions, is islanded into small networks so that the smaller networks can continue with power availability with their own generation capacities. This way total collapse is avoided.

The key parameters for detecting grid disturbances are:

- rate of change of frequency (df/dt)
- Over / Under voltage
- Over / Under Frequency

- Heavy fault current which flows from the substation to grid
- reverse power flow from substation to grid
- large unbalance in grid voltage
- Vector shift in grid voltage

It is advisable to have a protection scheme to monitor all the above parameters – particularly for a transformer close to a generating station. It will help in islanding the power station from grid disturbances.

10.0 **Advantages of Numerical relays in Transformer Protection :** It has been a practice to use electro-mechanical / solid state relays relays for all above protections. The present trend is to use Numerical relays which offer many advantages as shown in the following table, over the earlier technology.

ADVANTAGES OF NUMERIC RELAYS

PARAMETER	*NUMERIC*	*CONVENTIONAL*
ACCURACY	1%	5% / 7.5%
BURDEN	< 0.5 VA	> 5 VA
SETTING RANGES	WIDE	LIMITED
MULTI FUNCTIONALITY	YES	NO
SIZE	SMALL	LARGE
FIELD PROGRAMMABILITY	YES	NO
PARAMETER DISPLAY	YES	NO
SYSTEM FLEXIBILITY	YES	NO
CO-ORDINATION TOOLS	MANY	TWO
COMMUNICATION	YES	NO
REMOTE CONTROL	YES	NO
SPECIAL ALGORITHMS	MANY	LIMITED
SPECIAL PROTECTIONS	YES	NO
SELF DIAGNOSTICS	YES	NO

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The usual worry that Numerical relays are very expensive is now removed- continuous production improvement techniques have made numerical relay affordable – some times cheaper from the over all protection perspective. Above all, with features listed as above, Numerical relays are more user friendly and are gaining popularity every where.

11.0 **Conclusion** : Transformer protection plays a major role in ensuring consistent power transmission and distribution. This paper is a brief attempt to bring out the various protections required for transformers. The protections are based on size and location. Numerical relays offer better solutions for transformer protection.

L&T offers the following state of art numerical protective relays for transformer protection:

1. Three phase thermal + over current + Earth fault relay IM30T
2. Percentage biased transformer differential relay
   MD32T- For two winding transformers with one REF element built in
   MD33T- For three winding transformers
3. Three phase voltage/Frequency and zero sequence voltage relay with vector surge protection-UM30A

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