Power Transformer Ratings' Calculation and Analysis - IEEE C57.91-1995

An Online Continuing Education Course for Engineers

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Power Transformer Ratings' Calculation and Analysis - IEEE C57.91-1995

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Agenda:

- Introduction
- Transformer Types
- Turn Ratio
- Voltage Regulation
- Transformer Protection
- Transformer Ratings' Categories
- Intro to IEEE C57.91-1995 "IEEE Guide for Loading Mineral-Oil-Immersed Transformers
- Insulation System
- 24 Hour Temperature Cycle
- Load Cycle
- The Per-unit of Normal Life vs. Hottest Spot Temperature
- Cooling
- Continuous Rating
- Increasing Loss of Life %
- Increasing Hot Spot Temperature
- Lowering the Ambient Temperature Cycle
- 100% Load Factor
- Limited Time Rating

Introduction

As the name implies, the function of the transformer is to "transform", or change a certain value between two points. There are various transformer types, we will focus on two main types, step-up and step-down transformers; step-down transformers refer to transformers where the secondary voltage is lower than the primary voltage; step-up transformers refer to transformers where the primary voltage is higher than the secondary voltage, mainly referred to as generator step-up transformer (GSU).

Power is usually generated around 11-22 kV, let's call this medium voltage (different books define low, medium and high voltage differently). Generators are usually located far away from the load center, mainly due to:

- Cheaper real estate further from the load center vs. expensive real estate near the load
- Emissions regulations close to city centers
- State/city regulations with respect to industrial load and generators
- Near a water supply, i.e. river, so that the water can be used for cooling.

The real and reactive power could be coming from a power plant that is hundreds of miles away or few feet away; power will be transmitted via:

- Overhead transmission towers
- Underground transmission cables.

Underground cables are much more expensive than overhead feeders. After the power is generated, it is connected to the transmission system via a GSU (generator step-up transformer). As the name implies, the function of this transformer is to step-up the output of the generator (11-22 kV) to a transmission/sub-transmission voltage, i.e. 345-500 kV.
Why do we need to raise the voltage? The reason we transmit power at higher voltage is to reduce losses, where losses = I^2R, where I is the current, the load generated and R is the resistance. As seen, losses are a function of the square of the current, as a result it is not practical or cost effective to transmit power at lower voltages, this can be clearly explained via P = VI; ignoring losses, the same real power (P) will make its way from generation to your house; lowering the losses require lowering current, thus the voltage will be raised by the same factor to keep the same amount of power.

Transformer Types:
The difference between step-up and step-down transformer is in the primary and secondary turn ratios. This course will not discuss the transformer theory - instead we will focus on ratings.

Again, ignoring eddy current, hysteresis and other transformer loses, power entering the transformer equals power leaving the transformer, or the power entering the primary transformer winding is equal to the power leaving the secondary winding.

Turn Ratio:
Pin = Pout → $V_1 I_1 = V_2 I_2 = N$ or $V_1/ I_2 = V_2/ I_1 = N_1/N_2$

$$\frac{V1}{V2} = \frac{N1}{N2} = \frac{I2}{I1}$$

V1 is the primary voltage, N1 is the primary turn ratio, V2 is the secondary voltage, N2 is the secondary turn ratio; for step-down transformers, the secondary voltage is lower than the primary voltage:

$$V2 = \frac{V1\,N2}{N1}$$

$\frac{N1}{N2} = \mathrm{N}$ N is known as the turn ratio.

For a step-down transformer, V_2 is lower than V_1, as a result, the primary turns N_1 is greater than the secondary turns N_2.

$$V2 = V1/\ \mathrm{N}$$

For the step-up transformer, the opposite is true, the primary turns N_1 is smaller than the secondary turns N_2.

Voltage Regulation:
Transformers transform the voltage between two points as indicated prior; another major critical function is the voltage regulation. This is accomplished via two main components:

- LTC – Load Tap Changer
- NLTC – No Load Tap changer (sometimes known as De-energized Load tap Changer)

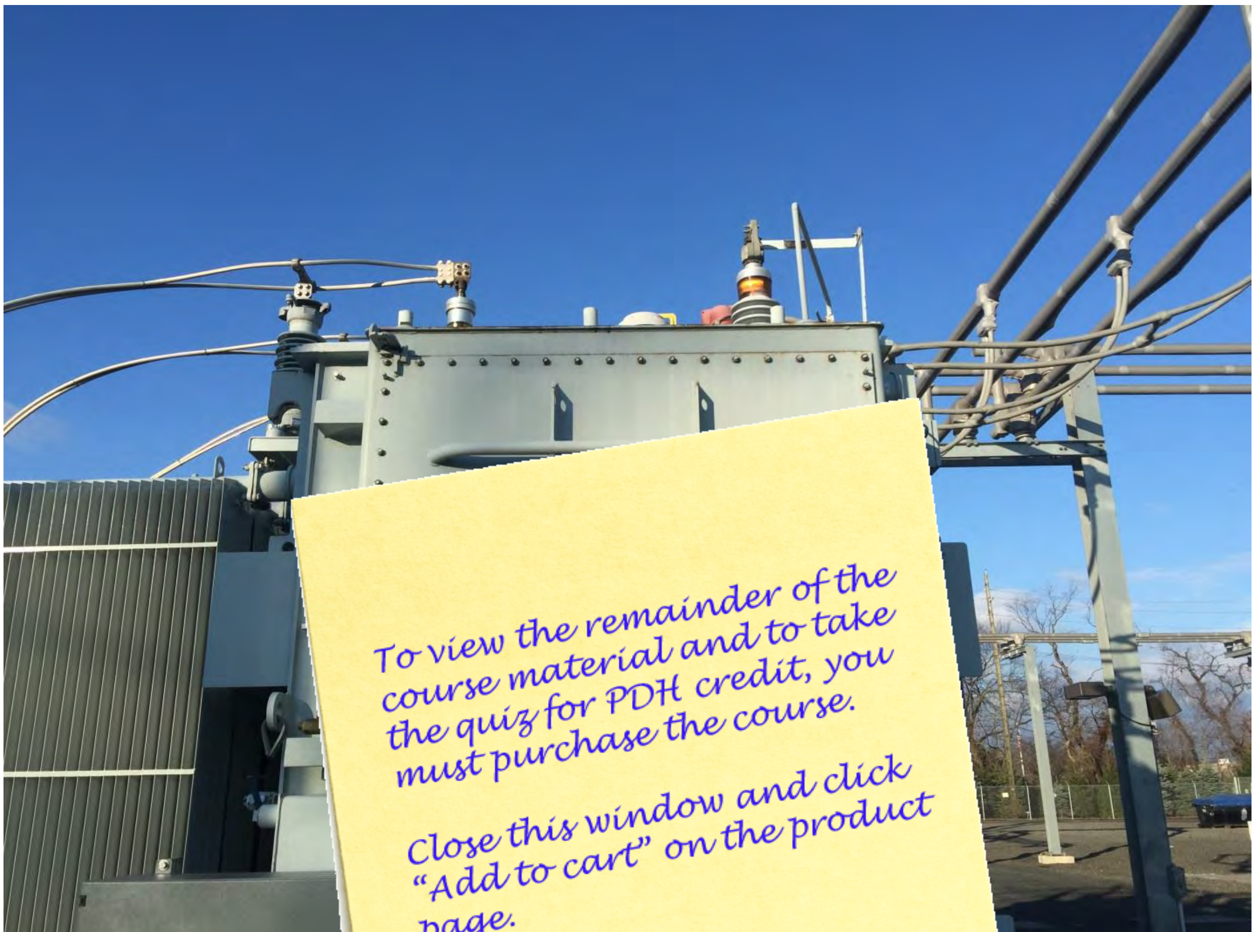
LTC and NLTC are the means by which the transformer is mechanically able to regulate the voltage; depending on the transformer design, the LTC can be installed either on the high (primary) side or the low (secondary) side. As implied by the name, the LTC regulation occurs under load (while supplying the customer load without any momentary interruption), while the NLTC regulation occurs while de-energized (transformer is removed from service, thus interrupting the customers connected to that transformer in order to make a tap adjustment). For now, treat the LTC as a motor that operates under oil as a result of the changes in voltage, i.e. if the voltage drops, the LTC will adjust to meet the expected voltage and if the voltage is high, then the LTC will regulate the voltage by lowering the voltage.

LTC is a regulation device that is known as “step-voltage regulation”, because the LTC moves in steps to regulate the voltage and each step the LTC takes, the voltage will either increase or decrease by a pre-defined voltage percentage, i.e. if the LTC moves up, the secondary voltage will increase by 100 volts and vice versa.

LTC is comprised of several taps, typically 33 taps, where step zero is known as the "Neutral” position, there are 16 positive taps and 16 negative taps; the proper way of depicting this would be 16L/N/16R, where "L" refers to lowering the taps and "R" refers to raising the taps; an easy way to remember is that as LTC lowers the tap, the voltage gets lowered and as the LTC is raised, the voltage is raised. It is important to note that as the voltage is lowered on the low side, the voltage will be raised on the high side and vice versa, basically you cannot have the same voltage change on both the primary and secondary voltage simultaneously, as the voltage on one side goes up, the opposite effect will occur on the other side.

The voltage regulation of the LTCs are typically +/-8%, +/-10% or +/-12%; that means that the LTC have the capability to increase the voltage by 12% or reduce the voltage by 12%, so the voltage regulation range is 24% (-12% to 12%) and the total taps is 32 (16L to 16R), therefore the voltage/step is: 24%/32 = 0.75% voltage per step.

Some transformers do not have LTCs, as a result, they rely on other means to regulate the voltage, i.e. cap banks/voltage regulators installed on the feeders or in the substation. The reason some transformers don't have LTCs is either due to space limitation (below is a picture showing the LTC compartment that is mounted on the transformer) or they have other means to regulate or for financial reasons, as transformers equipped with LTCs are more expensive than others without LTCs.



Transformer Protection:

In the electric power syste ... mer, transformer for short, is the most exper ... transformer. There are various protection types: