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Advance OLTC Control for Improving Power System Voltage Stability

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Abstract: The main purpose of the automatic voltage regulator (AVR) for power transformers with on-load-tap-changer (OLTC) is to keep the voltage on low voltage (LV) side of power transformer within apreset dead band. Originally AVR was designed to compensate for the voltage drop across power transformer impedance caused by flow of the load current. Therefore an AVR shall react an change position of OLTC in accordance with LV side load variations. However, the AVR will as well react on abnormal voltage variations on the high voltage (HV) side of the power transformer. Sometimes such AVR behavior is not desirable because it just further increases the total load on the HV system (i.e. transmission system). Especially, such behavior shall be prevented during critical operation states of the transmission system, such as a slow power system voltage collapse. Using transformers and tap changers to see how the voltage works in an electric system and analyze the relationships with other aspects of the system's performance, like power losses or tap changer operation. The main purpose of the automatic voltage regulator (AVR) for power transformers with on-load tap-changer (OLTC) is to keep the voltage on low voltage side of power transformer within a preset dead band.

Keywords: Power Transformer, On-load Tap Changer, AVR, Low Voltage Variation, Change Positions, OLTC Control.

I. INTRODUCTION

When the load in a power network is increased the voltage will decrease and vice-versa. To maintain the network voltage at a constant level, power transformers are usually equipped with an on load tap changer (OLTC). The OLTC alters the power transformer turns ratio in a number of predefined steps and in that way changes the secondary side voltage. Each step usually represents a change in LV side no-load voltage of approximately 0.5-1.7%. Standard tap changers offer between ± 9 to ± 17 steps (i.e. 19 to 35 positions).The automatic voltage regulator (AVR) is designed to control a power transformer with a motor driven on-load tap-changer. Typically the AVR regulates voltage at the secondary side of the power transformer. The control method is based on a step-by-step principle which means that a control pulse, one at a time, will be issued to the on-load tap-changer mechanism to move it up or down by one position.

The pulse is generated by the AVR whenever the measured voltage, for a given time, deviates from the set reference value by more than the preset dead band (i.e. degree of insensitivity). Time delay is used to avoid unnecessary operation during short voltage deviations from the pre-set value. When the load in a power network changes it consequently affects voltage profile at load end. To maintain the load voltage within permissible limits, Power transformers are equipped with tap changing system. The tap changer alters transformer turns ratio in a number of predefined steps which results change in secondary side voltage (Load end).On load tap changing power transformers are an essential part of any modern power system ,since they allow voltages to be maintained at desired levels despite load changes.

The problem with conventional tap changer is its mechanical structure of complicated gear mechanisms of selectors, diverters and switches. The on-load tap changer (OLTC) has a significant influence on voltage stability. Voltage stability is the ability of a power system to maintain steady acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage. The main factors causing instability are the inability of the power system to meet demand for reactive power. A large number of distribution systems have run into problems such as poor voltage regulation, poor power factor, high losses and poor efficiency, overloading and less reliability for continuity of supply. The main function of the AVR (automatic voltage regulation) system is to ensure the security and stability operation of the power system, and ensure that the voltage and power factor of the specific buses are within the preset values, and also minimize line reactive transmission, reduce the power loss of the grid due to unnecessary reactive power flow. The AVR system provides real time automatic control for the on-load transformer tap changer (OLTC).

Most network power transformers/autotransformers and large voltage regulators are equipped with manual or automatic on-load tap-changers (OLTC) so that the voltage ratio and hence the secondary voltage may be varied as the load supplied by the transformer changes. Manual control may be used for transformers whose tap positions are changed only infrequently, such as transformers at generating stations. Manual control may be local, at the substation or remote, at a central control center. Automatic control is provided on transformers in the high-voltage networks. On load tap changers (OLTCs) maintain a constant transformer secondary voltage given changing primary voltage and transformer load. A common OLTC arrangement has 16 taps above and below the nominal tap (33 total taps), and each tap adjusts the transformer turns ratio by 0.375 percent. When the transformer's secondary voltage is outside the permitted margin, thus motors change the tap position and regulate secondary voltage while still supplying the load. An OLTC control measures the secondary voltage and sends raise and lower signals to the OLTC motor to control secondary voltage.

The OLTCs interact with each other whenever there is a voltage deviation on the system. Traditionally, each voltage level is graded with the next, using simple time delays. This ensures that the upstream tap changers take priority over the downstream units and make their tap changes first. This prevents hunting and reverse actions by lower-level tap changers. Unfortunately, the voltage control can become crude and inefficient at small voltage deviations. The new control strategies have been developed to improve the coordination of the AVR system and hence provide an improved quality of supply for consumers.

II. VOLTAGE CONTROL WITH ON-LOAD TAP-CHANGER

The ratio of a transformer can be changed by adding turns to or subtracting turns from either the primary or the secondary winding using a load tap-changer (LTC). The LTC can be located at the primary or the secondary side of the transformer. The representation of a transformer equipped with an LTC and its equivalent diagram is shown in Figure .1. Notation I, U, n and y in the figure indicates current, voltage, normalization of the transformer turn ratio and transformer admittance, respectively; and subscripts p and s indicate primary and secondary sides of the transformer, respectively. There are two types of LTC, no-load tap-changer where the transformer ratio can be changed only when the transformer is de-energized, and on-load tap-changer (OLTC) where changing of the tap position is possible also when the power transformer is carrying load. This paper will only deal with OLTC that has been widely used in voltage regulation for many decades. The OLTC basic arrangement is shown in Figure 2. The OLTC controller keeps the substation secondary bus voltage U1 constant within the range

$$ULB < U1 < UUB \quad (3\text{-}4)$$

Where,
ULB = Uset – 0.5UDB is the lower boundary voltage
UUB = Uset + 0.5UDB is the upper boundar
Uset is the set point voltage and UDB is the deadband.

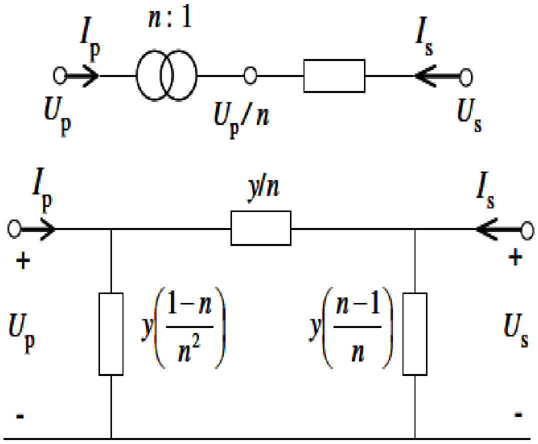


Figure1. OLTC representation and its equivalent diagram.

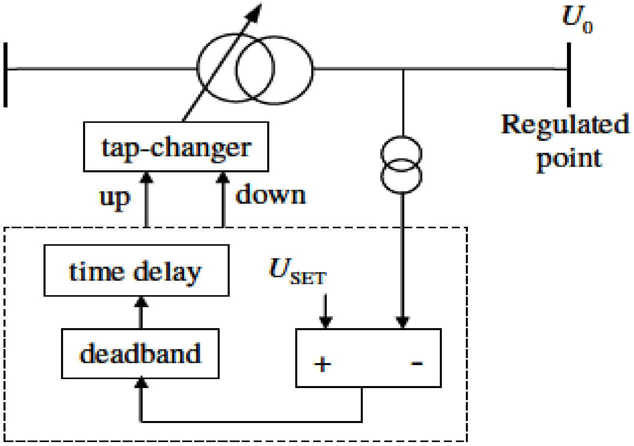
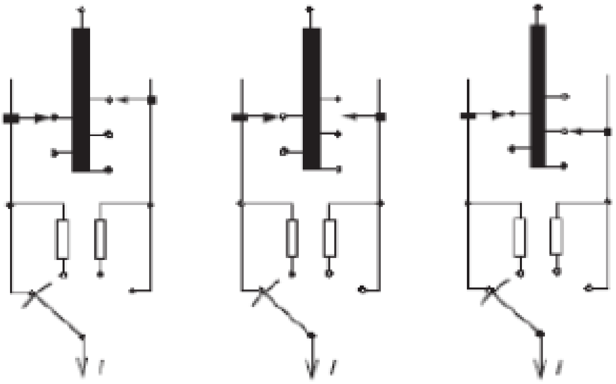


Figure 2. Basis OLTC arrangement.

III. OLTC SWITCHING SEQUENCE

In oil-type OLTCs there are two types of switching principles used, the diverter which consists of an arcing switch and a tap selector, and the selector which consists of an arcing tap switch [1]. Diverter type OLTCs change taps in two steps: “First, the next tap is pre-selected by the tap selector at no load (Then the arcing switch transfers the load current from the tap in operation to the pre-selected tap” [1]. The tap selector is operated directly by the OLTC drive mechanism, whereas the arcing switch is operated by a stored energy spring.



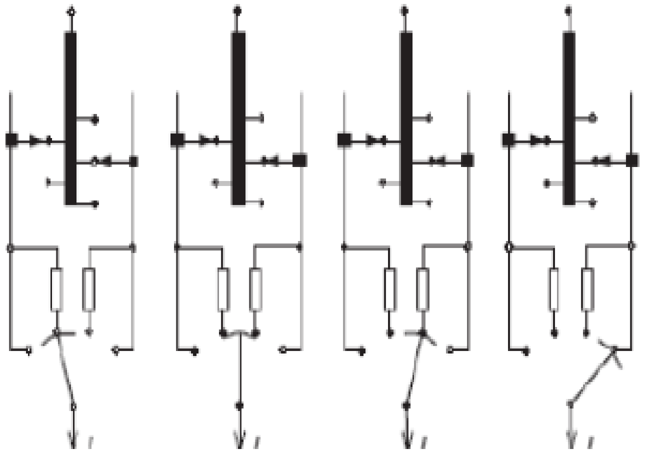


Figure3. LTC representation and its equivalent diagram.

A. Automatic OLTC Control Principles for Single Transformer

A typical AVR measures the busbar voltage (UB) at the power transformer LV side, and if no other additional features are enabled (i.e. line drop compensation) this voltage is used for voltage regulation. The voltage control algorithm then compares UB with the set target voltage (Uset) and decides which action should be taken. Because this control method is based on a step-by-step principle, a deadband □U (i.e. degree of insensitivity) is introduced in order to avoid unnecessary switching around the target voltage. The deadband is typically symmetrical around Uset as shown in Figure 4. Deadband should be set to a value close to the power transformer.s OLTC voltage step. Typical setting is 75% of the OLTC step.

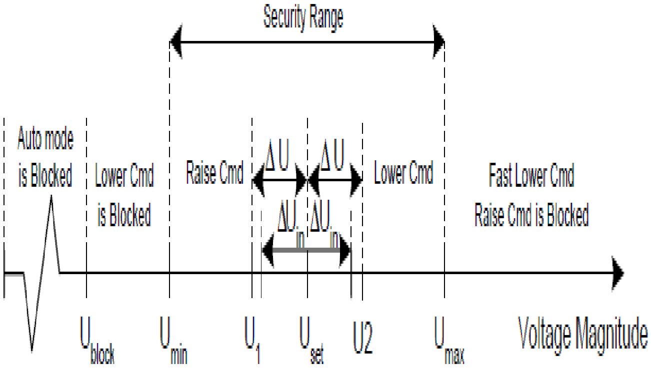


Figure4. Typical AVR Voltage Scale for automatic voltage control.

During normal operating conditions the busbar voltage UB, stays within the deadband. In that case no actions will be taken by the AVR. However, if UB becomes smaller than U1 or greater than U2 (see Figure 4), an appropriate lower or raise timer will start. The timer will run as long as the measured voltage stays outside the inner deadband. If this condition persists for longer than a preset time, the appropriate LOWER or RAISE command will be issued. If necessary, the procedure will be repeated until the busbar voltage is again within the inner deadband. The main purpose of the time delay is to prevent unnecessary OLTC operations due to temporary voltage fluctuations. The time delay may also be used for OLTC co-ordination in radial distribution networks in order to decrease the number of unnecessary OLTC operations. This can be achieved by setting a longer time delay for AVRs located closer to the end consumer and shorter time delays for AVRs located at higher voltage levels.

B. Selection of Load Tap Changer

The selection of a particular OLTC will render optimum technical and economic efficiency if requirements due to operation and testing of all conditions of the associated transformer windings are met. In general, usual safety margins may be neglected as OLTCs designed, tested, selected and operated in accordance with IEEE and IEC standards are most reliable. To select the appropriate OLTC the following important data of associated transformer windings should be known:

- MVA-rating
- Connection of tap winding (for wye, delta or single-phase connection)
- Rated voltage and regulating range
- Number of service tap positions
- Insulation level to ground
- Lightning impulse and power frequency voltage of the internal insulation [1]

The following OLTC operating data may be derived from this information:

- Rated through-current: Iu
- Rated step voltage: Ui
- Rated step capacity: Pst = Ui × Iu and the appropriate tap changer can be determined:
- OLTC type
- Number of poles
- Nominal voltage level of OLTC
- Tap selector size/insulation level
- Basic connection diagram

If necessary, the following characteristics of the tap changer should be checked:

- Breaking capacity
- Overload capability
- Short-circuit current (especially to be checked in case of phase shifting applications)
- Contact life [3]

IV. SIMULATION MODEL OF OLTC REGULATING TRANSFORMER

In this design, three-phase two winding 230/33 kV, 85 MVA OLTC regulating power transformer is used for electric arc furnace. This OLTC transformer connections are high voltage Y-ground (Yg) and low voltage delta. The on-load tap changer (OLTC) uses a tap winding (regulating winding) in series with winding 1(Yg) to vary the U_1 voltage in 16 deltaU steps from tap -8 to +8 (17-positions). Tap position 0 to correspond to nominal voltage ratio.

The transformer voltage ratio U_2/U_1 (p.u) is given by:

$$U_2/U_1 = 1/(1 + \text{Tap position} \times \text{deltaU})$$

Where: $-8 \leq \text{Tap position} \leq +8$

In automatic mode, (voltage regulator 'on'), the signal applied at the V_m input is monitored and the voltage regulator asks for a tap change if:

abs ($V_m - V_{ref}$) >deadband/2 during a time t > delay

Voltage step deltaU per tap = 0.01875 p.u

Initial tap position = -4

Tap selection time = 3 ~ 10 s

Tap transient time = 40 ~ 60 ms

Transfer resistance = 5 ohm

Voltage regulator = 'on' mode

V_{ref}= 1.04 p.u

DeltaU = 0.0375 p.u

Delay time = 1 s

A. Block Model of OLTC Regulating Transformer

This model is a three-phase two-winding power transformer using a on-load tap changer (OLTC) for regulating voltage on a transmission or distribution system. Controlling voltage on a transmission system will affect primarily flow of reactive power, which, in turn, will affect the power transfer limits. Although the regulating transformer does not provide as much flexibility and speed as power-electronics based FACTS, it can be considered as a basic power flow controller. This is why it has been included in the facts library. The dynamic performance of the regulating transformer can be enhanced by using a thyristor-based tap changer instead of a mechanical tap changer. As this model is a phasor model which does not implement the details of current commutation from one tap to the next tap, can be use it to model a thyristor-based tap changer.

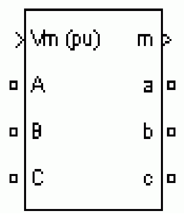
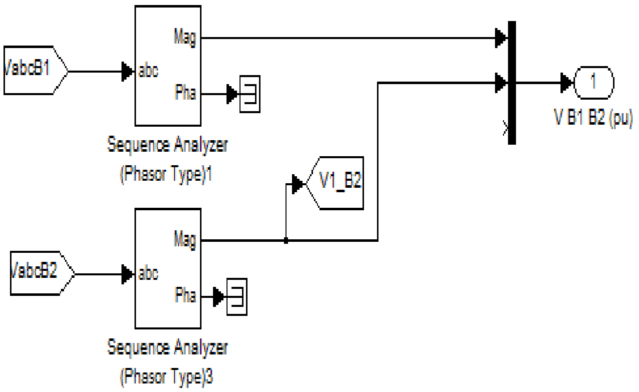


Figure5. Block Model of Three-phase Two-winding Transformer.

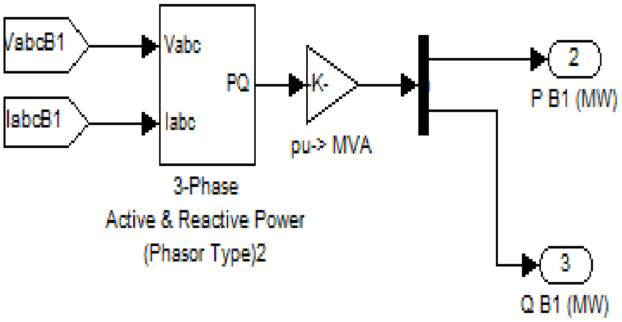
The regulating transformer is usually associated with a control system which regulates voltage at the transformer terminals (side 1 or side 2) or at a remote bus. Such a control system is provided in the Three-Phase OLTC Regulating Transformer (Phasor Type) block. Then connect at the Vminput of the block a simulink signal which is usually the magnitude of the positive-sequence voltage (in pu) to be controlled, but it can be any signal. The control system will adjust automatically the tap position until the measured voltage V_m is equal to the reference voltage V_{ref} specified in the block menu. The voltage regulator is a hysteresis type regulator. Each time a tap change is required, the regulate sends a pulse either to the Up or Down input of the Tap Changer Controller. Look under the block mask to see how these control blocks are built. The regulator will ask for a tap change if

$$|Vm - Vref| > \text{Deadband}/2 \text{ during a time } t > \text{Delay}$$

Where: Vref, Deadband, and Delay are parameters of the voltage regulator.



(a)Voltage Signal



(b) Active and Reactive Power Signal

Figure6. Signal Processing Block Diagram of OLTC Regulating Transformer.

For the automatic voltage regulation, the winding is designed to adopt an OLTC. Typically the automatic voltage regulator (AVR) regulates voltage at the secondary side of the power transformer. The control method is based on a step-by-step principle. That is, a control pulse, one at a time, will be issued to the on load tap changing mechanism to move OLTC up or down by one step position. The connecting tap points of the windings for tap change can cause a thermal problem. Therefore, the tap selecting part of OLTC equipment was installed into the liquid nitrogen and the other parts were installed at room temperature as the conventional transformer did.

V. SIMULATION OF OLTC REGULATING TRANSFORMER

For installing tap points on the primary winding, Simulink model and simulation results are shown in the following Figures.

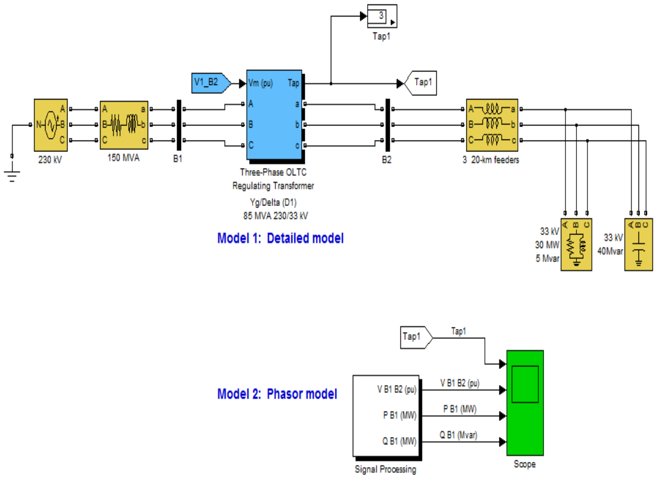


Figure7. Simulation of OLTC Transformer for 30 MW and 5 Mvar Load.

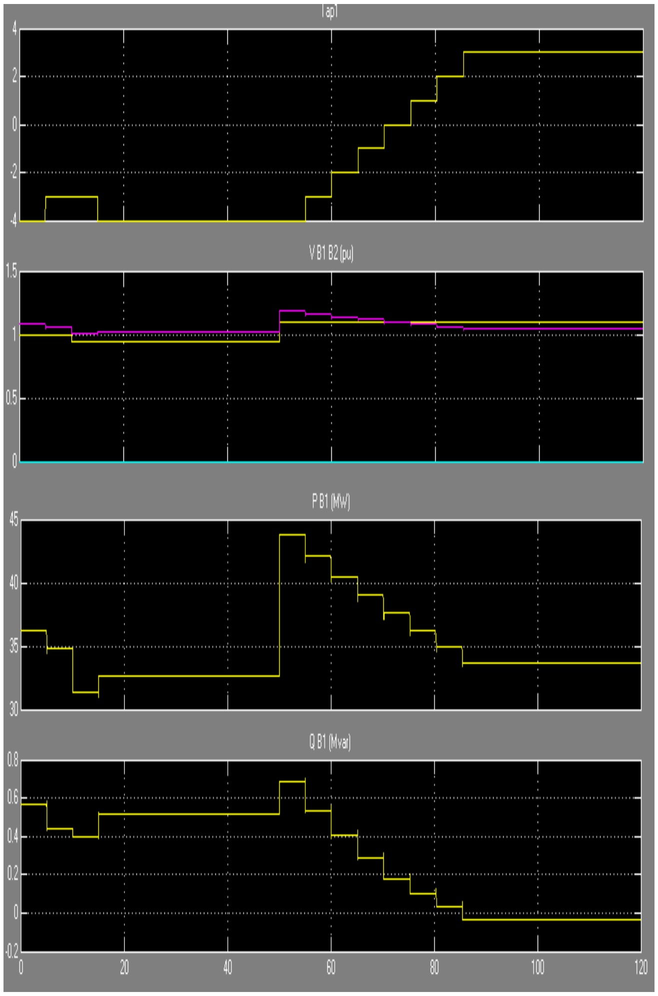


Figure 8. Simulation Results of OLTC Transformer for 30 MW and 5 Mvar Load.

Tap positions, high voltage (pink color) and low voltage (yellow color) p.u conditions, active power (MW) and reactive power (MVar) from high voltage side are also shown in the result Figures 7 to 12. In this simulation models, OLTC changes the power transformer's turns ratio in a number of predefined steps and the secondary voltage is changed by this. Each step usually represents a change of ±1.25 % in low voltage side. Figure (i) shows the tap changing positions in high voltage winding respect with the secondary load changes. H.V winding of power transformer is changed $230500/\sqrt{3} \pm 8\times1.25\%$ (17 positions) in each step changes ± 2881 V. In Figure (ii), low voltage (p.u) is stable from 50 ms at complex load and high voltage changes with respectively turn ratio. Active power (MW) and reactive power (MVar) conditions are also shown in Figure (iii) and (iv).

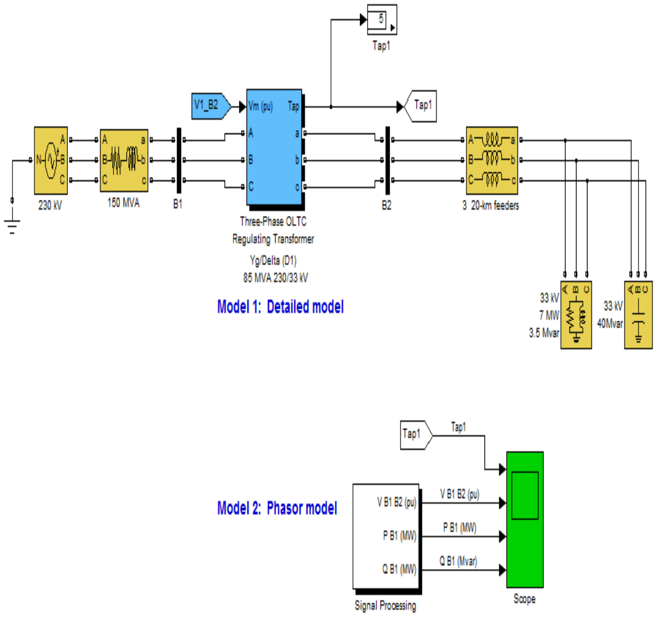
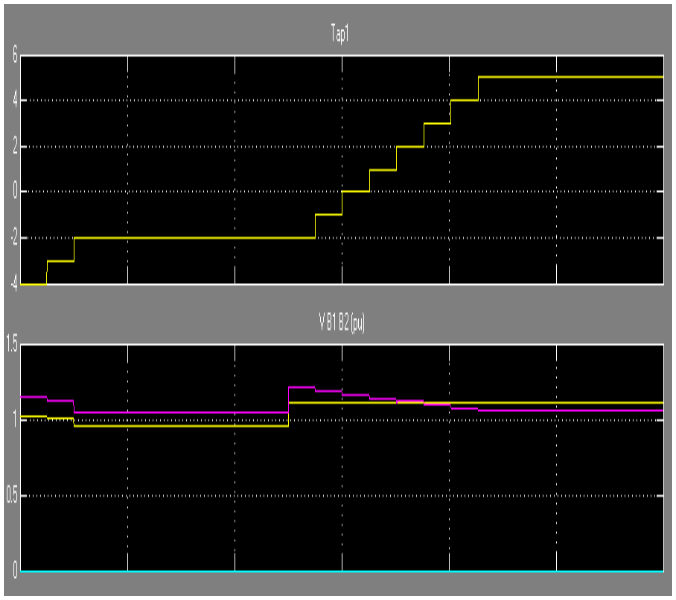


Figure9. Simulation of OLTC Transformer for 7 MW and 3.5 Mvar Load.



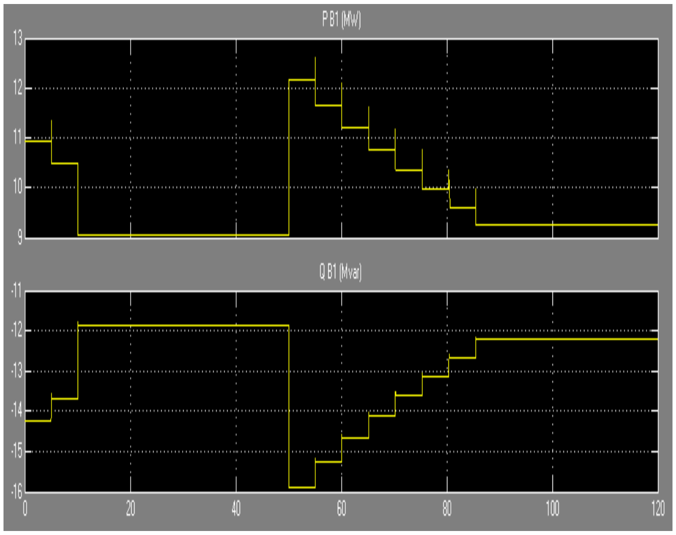


Figure 10. Simulation Results of OLTC Transformer for 7 MW and 3.5 Mvar Load.

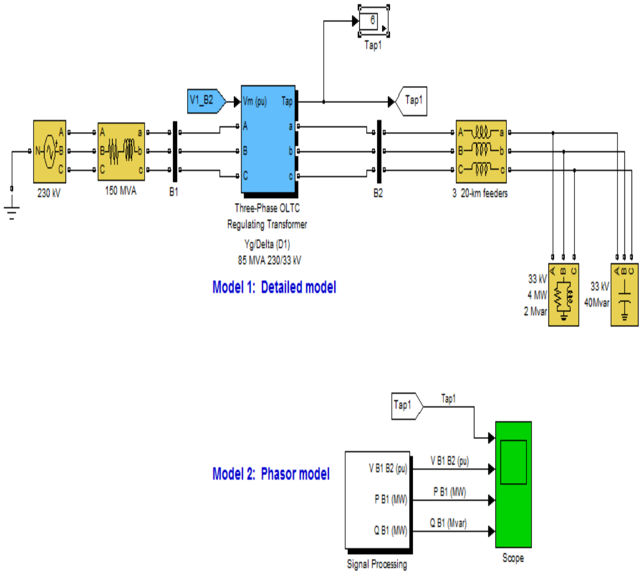
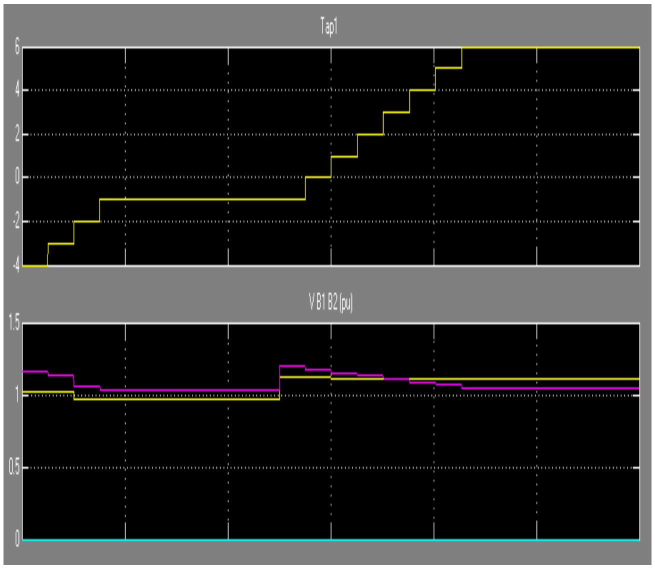


Figure 11. Simulation of OLTC Transformer for 4 MW and 2 Mvar Load.



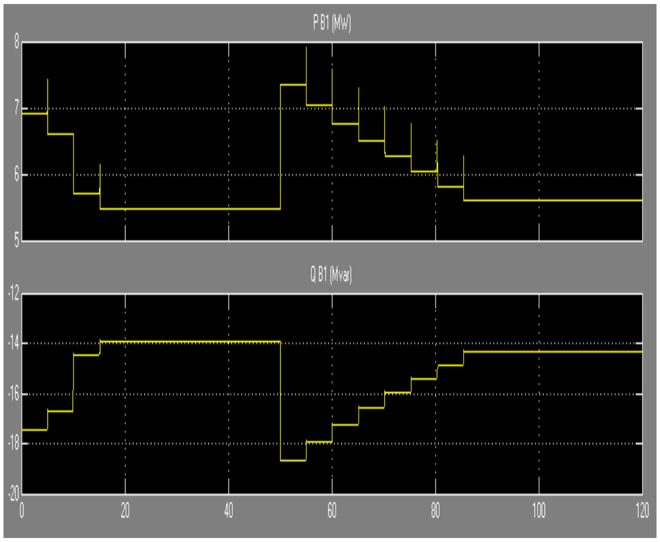


Figure12. Simulation Results of OLTC Transformer for 4 MW and 2 Mvar Load.

VI. CONCLUSION

This paper was intended for sample simulation results of OLTC regulating transformer. OLTC theory, operation and example application with Steel Mill are also described in this paper. This research is carried out using MATLAB programs performed on 17-taps OLTC transformer and then the simulation results show the effects of varying tap ratio by using tap changing transformer. Presently available technical solutions enable the production of OLTCs that are reliable and meet the same life expectancy as transformers. At the present time and for the foreseeable future, the proper implementation of the vacuum switching technology in OLTCs provides the best formula of quality, reliability and economy achievable towards a maintenance free design. The vacuum switching technology entirely eliminates the need for an on-line filtration system and offers reduced down-times with increased availability of the transformer and simplified maintenance logistics. All these together translate into substantial savings for the end-user.

VII. ACKNOWLEDGEMENT

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