ISSN: 2278 – 1323
International Journal of Advanced Research in Computer Engineering & Technology (IJARCET)
Volume 1, Issue 10, December 2012

Coordinated control ULTC power transformer with STATCOM for Voltage Control and Reactive Power Compensation

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Abstract: The static synchronous compensator (STATCOM) is one type of FACTS devices which resembles in many respects a rotating synchronous condenser used for voltage control and reactive power compensation. The STATCOM can increase transmission capacity, damping low frequency oscillation, and improving voltage stability. This paper presents a control block diagram of STATCOM for the voltage stability improvement. The SIMULINK / MATLAB software 'package' is used for simulation of test system. In this paper the STATCOM is connected with ULTC transformer to the 25KV line for a typical single machine infinite bus transmission system. The study demonstrates that STATCOM not only considerably improves voltage stability but also compensates the reactive power in steady state.

Keywords: FACTS, STATCOM, Voltage Stability, ULTC (under load tap changer).

I. INTRODUCTION

It is common to install a ULTC (Under Load Tap Changer) at the distribution substation to regulate load voltage against the variation of load demand [1]. Although components of the ULTC control system are simple devices, its overall system is complex due to the presence of nonlinearity such as time delay, dead band, etc. So the traditional approaches have difficulties in analyzing and controlling the ULTC control systems. Nowadays STATCOM Co-ordination control approach has been applied to control system design of ULTC. Recently STATCOM (Static Synchronous Compensator) is a mature technology ready to be adopted to complement the existing shunt capacitor or synchronous condenser for its versatile control capability [3]. It is a fast acting static reactive power compensator, which can damp out the power oscillations and cope with the voltage problem due to reactive power deficit.

There has been an approach to improve the voltage profile and reduce the number of tap operations by coordinating the ULTC and STATCOM (Static Synchronous Compensator). The motivation of this paper comes from the following considerations concerning the coordination of the STATCOM and ULTC.

1) Two devices have similar objectives. Although STATCOM is completely different from ULTC in that STATCOM actively injects reactive power into the bus to regulate the bus voltage, primary objectives are the same at the distribution substation.

2) Two devices have completely different time scales. STATCOM is very fast, but ULTC is very slow. STATCOM has a time scale of several milliseconds, but that of

ULTC is beyond several seconds. Since STATCOM has a fast dynamic characteristic, it responds to the electric load demand variation before ULTC starts to act. If the capacity of STATCOM is sufficient to cope with the variation of the voltage, the ULTC begins to operate only when the load voltage goes below the predefined reference voltage. It can, however, happen that STATCOM's regulation of the transformer primary side voltage retards the tap changing operation of the ULTC. The STATCOM cannot have a margin for controlling emergency. Based on the above observations this paper proposes a coordinated control system of an STATCOM and a ULTC at the distribution substation to reserve the operating margin of the STATCOM while improving the load voltage quality. The STATCOM controls the load voltage and the ULTC adaptively changes the time delay according to the operating state of the STATCOM. The interaction between the STATCOM compensation and the ULTC tap position is investigated. In order to reserve the operating margin of the STATCOM, time delay of the ULTC is adaptively changed according to the STATCOM operating condition.

II. CONVENTIONAL STATCOM V-I CHARACTERISTIC

A typical V-I characteristic of a STATCOM is depicted in Fig. 1. As can be seen, the STATCOM can supply both the capacitive and the inductive compensation and is able to independently control its output current over the rated maximum capacitive or inductive range irrespective of the amount of ac-system voltage. That is, the STATCOM can provide full capacitive reactive power at any system voltage even as low as 0.15 PU. The characteristic of a STATCOM reveals strength of this technology: that it is capable of yielding the full output of capacitive generation almost independently of the system voltage (constant-current output at lower voltages). This capability is particularly useful for situations in which the STATCOM is needed to support the system voltage during and after faults where voltage collapse would otherwise be a limiting factor.

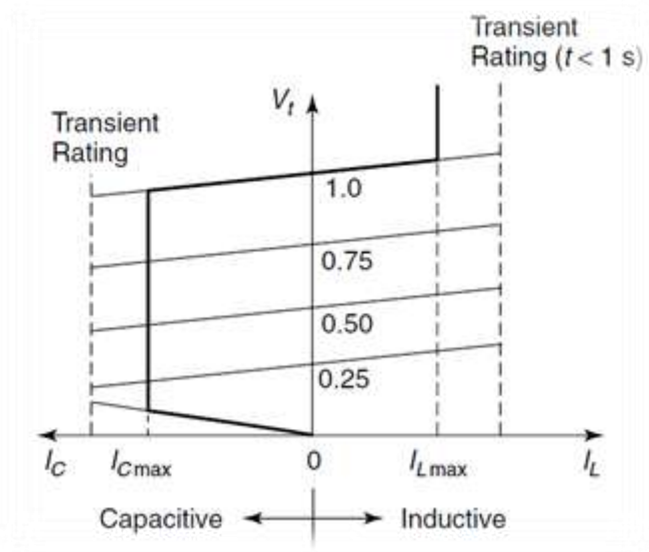

Fig.1. the V-I characteristic of the STATCOM [3].

III. DISTRIBUTION SYSTEM VOLTAGE CONTROL REQUIREMENTS

Voltage regulation is an important subject in electrical distribution engineering, because it is the utility's responsibility to keep the customers' service voltage (the voltage at the customer's meter, or the load side of the point of common coupling (PCC)) within the acceptable range. Here two of the benefits available with the application of distribution-level continuously-controlled reactive compensation by STATCOM (Static Synchronous Compensator) are:

1. The improvement of power quality, and
2. The increase in substation load ability [2] [6] [9] [10].

IV. COORDINATION BETWEEN PROPOSED STATCOM COTROLLER AND ULTC TRANSFORMER [4] [5]

Figure 2 shows the scheme of the proposed coordination controller.

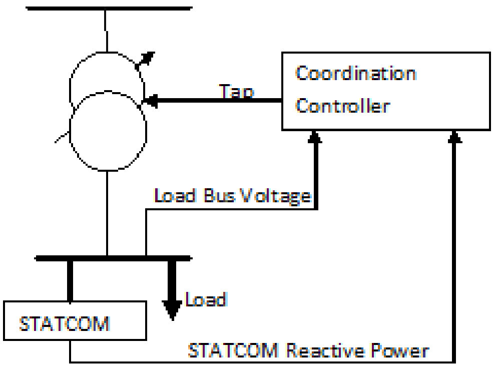

Fig.2. Proposed coordination Controller Scheme [16]

After a load change as a disturbance, the STATCOM supplies/absorbs required reactive power very quickly (nearly within 3 millisecond.) to keep the load bus voltage at the specified value, and then stabilizes at a steady-state operating point.
In order to make the STATCOM available for further system changes, the coordination controller forces the
ULTC to activate and be set at a tap position appropriate to nearly zero STATCOM output, while keeping the load bus voltage at the desired value.

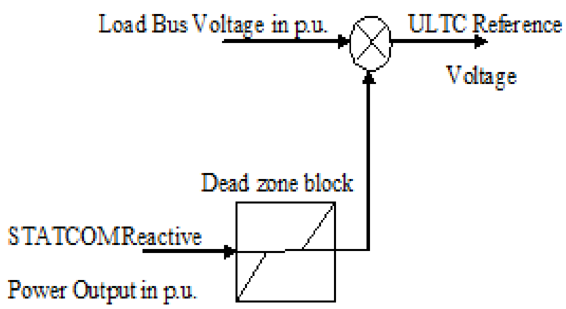

Fig.3. Coordination Controller Flow Diagrams

Figure 3 shows the coordination controller flow diagrams. As can be seen from this figure, a dead zone block is used to prevent oscillatory operation around the desired operating point. The Dead Zone block generates zero output within a specified region, called its dead zone. The lower and upper limits of the dead zone are specified as the Start of dead zone and End of dead zone parameters. The block output depends on the input and dead zone:
1. If the input is within the dead zone (greater than the lower limit and less than the upper limit), the output is zero.
2. If the input is greater than or equal to the upper limit, the output is the input minus the upper limit.
3. If the input is less than or equal to the lower limit, the output is the input minus the lower limit.
The reference voltage of the power transformer is the load bus voltage that needs to be kept at a desired value, for example 1 PU. When STATCOM output is nearly zero, the reference voltage is the load bus voltage, otherwise, the reference voltage is higher or lower than the load bus voltage, and hence the ULTC is forced to compensate the reactive power already supplied by STATCOM. By each tap changing, STATCOM decreases its output, so the final reference value approaches the load bus voltage.

V. SIMULATION RESULTS

The efficiency of the STATCOM and ULTC coordination controller with power system model is shown in Figure 4. The model simulation is done by MATLAB/SIMULINK ver. 7.4. this figure shows a 25 kV distribution network supplies continues power to a 36 MW /10 MVAR load (0.964 PF lagging) from a 120 kV, 1000 MVA system and a 120kV/25 kV ULTC regulating power transformer. Reactive power compensation is provided by a 10 MVAR capacitor bank at load bus. ULTC power transformer implements a 3-phase regulating transformer Rated 47 MVA, 120 KV/25 KV (Y/ Delta) with the ULTC connected on the HV side (120 KV). The ULTC regulating transformer is used to regulate power system voltage at 25 KV bus B4. Voltage regulation is performed by varying the ULTC transformer turn ratio. This system is obtained by connecting a tapped winding (regulation winding) in series with each 120/sqrt (3) KV winding on each 3-phase. Nine (9) ULTC switches uses to allow selection of eight (8) different taps (tap positions 1 to 8, plus tap zero (0) which provides nominal 120KV/25 KV ratio). A reversing switch included in the ULTC allows reversing connections of the regulation winding of transformer so that it is connected either additive (positive tap positions) or subtractive (negative tap positions). For a fixed 25 KV secondary voltage, each tap provides a voltage correction of +/- 0.01875 PU or +/-1.875% of nominal 120 KV load bus voltages. Therefore total 17 tap positions also including tap 0, allow a voltage variation from 0.85 PU (102 KV) to 1.15 PU (138 KV) by steps (per tap) of 0.01875 PU (2.25 KV). The positive sequence voltage measured at bus B3 is provided as input to the voltage regulator. The Vref(reference voltage) is set to 1.0 PU. In order to start simulation with 25KV voltages close to 1.0 PU at load bus B4, the initial tap position is set at -1, so that the transformer is boosting the voltage by a factor 1/ (1- 0.01875) =1.019PU. The tap transition is performed by temporarily short-circuiting two adjacent transformer taps through resistors 5 ohm resistances and 60 milliseconds transition time. The phasor model is built with current sources simulating the transformer impedance which depends on winding resistances (Rw), leakage reactance (XL) and tap position. The model use a voltage regulator that generates pulses at the 'Up' or 'Down' outputs.the orders of a tap change either in the positive or negative direction. The voltage regulation depends on the specified dead band (DB = two times the voltage step or 0.0375 PU). This means that the maximum voltage (Vm) error at bus B4 should be 0.01875 PU. As long as the maximum tap number is not reached (-8 or +8) and voltage should stay in the range: (Vref-DB/2< V<1.04+DB/2) = (1.021< V< 1.059).

As tap selection is a relatively slow mechanical process (4 second/tap as specified in the 'Tap selection time(TST)' parameter of the block menus), the simulation Stop time is set to 2 minute (120 seconds). STATCOM rating is 15 MVAR and its droop is 3%.

Fig.4 shows the simulation results of the sample network without the fixed capacitors. At t=20 Seconds, the breaker closes and an 18MW/5MVAR load connects to the load bus. This causes the voltage of bus B4 decreases and STATCOM generates the required capacitive reactive power (Qc) to keep the bus voltage at the desired value. After some delay about the coordination controller instructs ULTC to change their tapping and STATCOM relatively decreases its output.

This simulation procedure continues until the STATCOM output (Q_m) reaches to nearly zero. The fig.5 shows the voltage of bus B4 is kept constant due to the STATCOM fast operation while the voltage of HV changes for voltage regulation. At t=60 Second the breaker opens and the load is disconnected then STATCOM absorbs reactive power and avoids voltage increase at the load bus B4. In this case ULTC also operates and helps STATCOM to return back to the standby condition. In this case, the initial tap position (ITP) for nearly zero (0) STATCOM output at the start of simulation is -4. As can be seen from Figure 6, the initial tap position is -1. In this case, the ULTC and STATCOM perfectly operate in coordination with each other. Fig.7 shows the STATCOM and ULTC operation without coordination. In this figure shown STATCOM remains at its limit and jumps from a high capacitive to a high inductive value at t=60 Second. This case indicates the necessity to coordinate the ULTC of regulating transformer operation with STATCOM. Fig.8 shows the independent operation of STATCOM and ULTC of the sample power system network without the fixed capacitor bank. In this case, the initial tap is -4 in order to provide the required reactive power to compensate the load bus voltage. At t=20 Second the breaker close and the bus load increases and motivating the STATCOM to operate and provide required reactive power to the load bus. In this case STATCOM cannot supply the required reactive power; therefore ULTC operates and moves to tap -6. STATCOM output decreases a small value but not to standby condition. As can be seen from Figure 9, the STATCOM and ULTC coordinated operation for a light load change. The tap initial position (ITP) is -4 and changes to -5 in order to compensate for STATCOM output to return to standby condition. In this case the role of dead zone block is salient here to avoid oscillatory operation of ULTC of regulating power transformer around the desired suitable value.

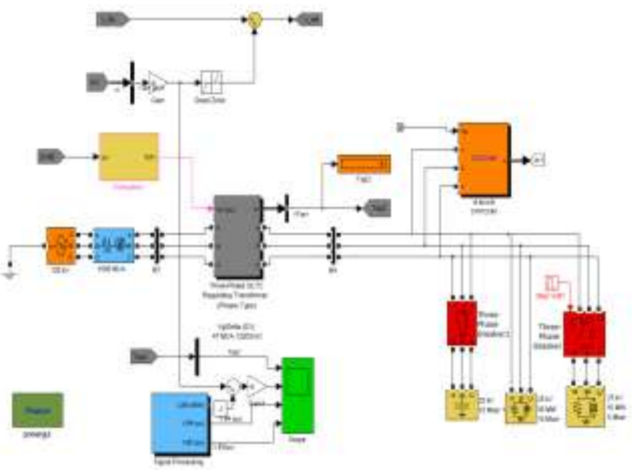

Fig.4. Working power system model set-up in MATLAB/SIMULINK

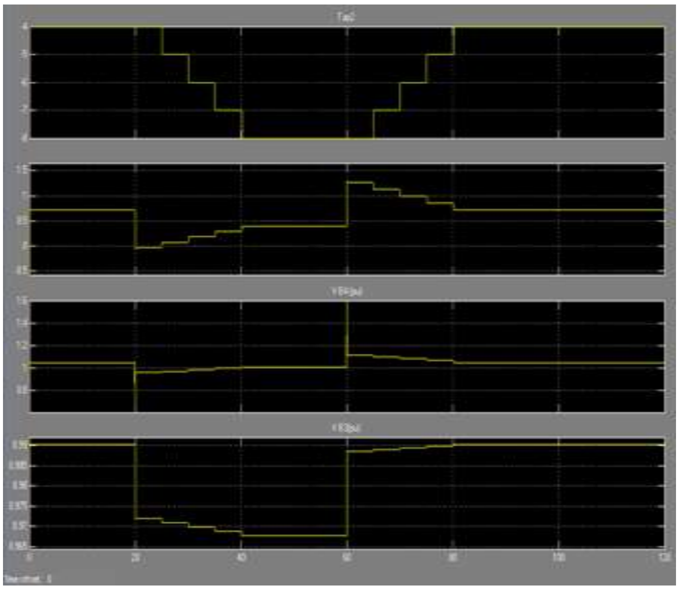

Fig.5. Coordination of STATCOM and ULTC without fixed capacitor

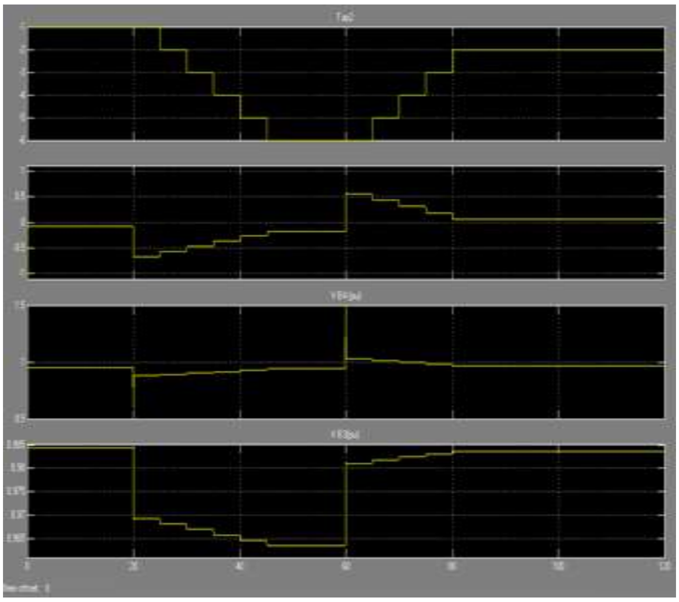

Fig.6. **Coordination of STATCOM and ULTC with fixed capacitor**

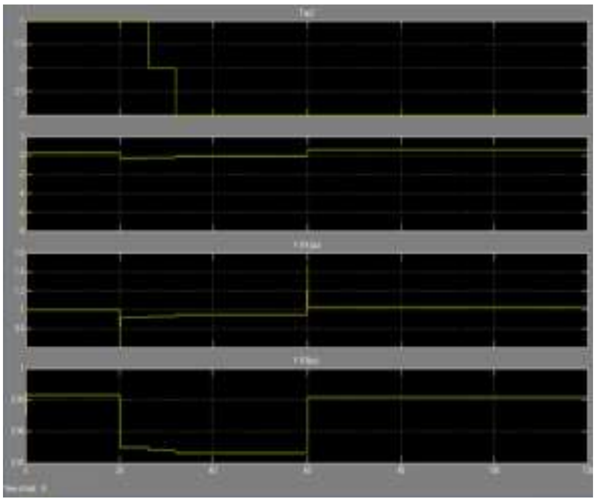

Fig.7. **Operation of STATCOM and ULTC without coordination (with fixed capacitor)**

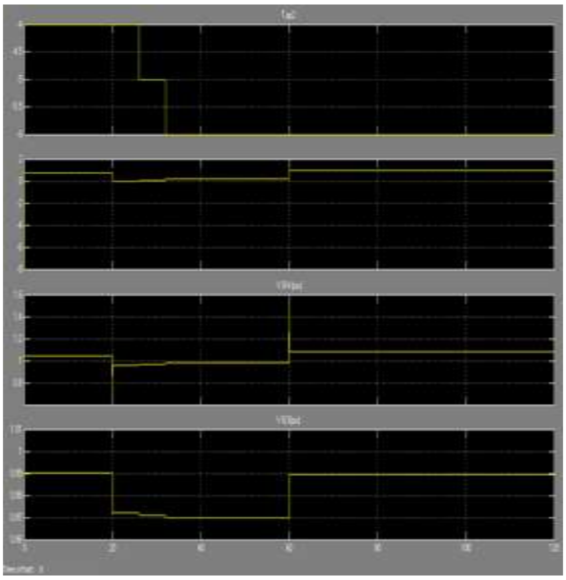

Fig.8. **Operation of STATCOM and ULTC without coordination (without fixed capacitor)**

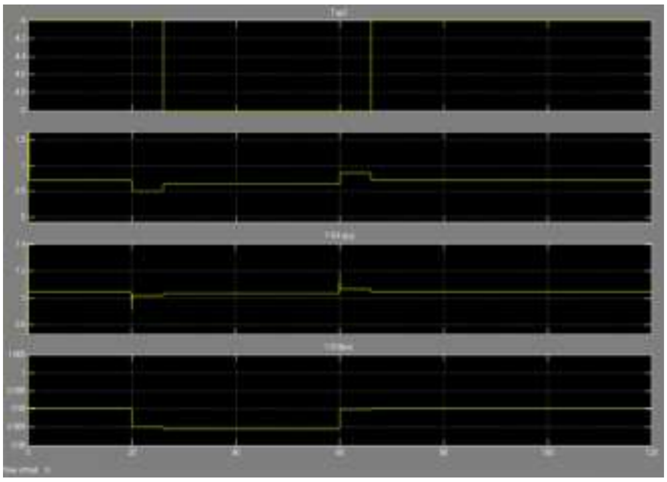

Fig.9. **Coordination of STATCOM and ULTC for a light load change (without fixed capacitor)**

VI. CONCLUSION

The proposed coordinated control system in this paper has the following merits over the conventional system-

1. It can reserve the STATCOM operating margin without increasing the tap operation.
2. The load voltage profile and quality are improved.

This Paper Shows the Additional Benefits That is the coordinated control avoids ULTC oscillatory operation by applying a dead zone block in STATCOM coordination control system with ULTC power transformer for better & fast Voltage Control and Reactive Power Compensation.

VII. Acknowledgements

I would like to thank my guide, Mr. A. K. KORI (Asso. Prof.) at JEC Jabalpur (MP), for his continuous guidance and support not only in my mastered study, but also in student life. His dedication in teaching, tutoring, and assistance to me is greatly appreciated.

I am very thankful to Dr. A. K. SHARMA (H.O.D.) at JEC Jabalpur (MP) for her inspirational instructions.

I am also thankful to all the professors, faculty members and students in the JEC Jabalpur, including those already graduated. Your friendship, encouragement, and help were indeed beneficial to my studies and research work.

Finally, I would like to express my appreciation and love to my Uncle, Mr. Uday Singh, and my parents Mr. Ugrasen Singh and Mrs. Rambai Singh. They have always loved me, supported me, and encouraged me unconditionally.

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VIII. APPENDIX

The data for various components used in the MATLAB model of Figure 4. (All data are in PU unless specified otherwise; the notations used are as in Sims Power System toolbox): SOURCES: Base voltage- 120 kV, Phase to phase RSM voltage- 500 kV x 1.078, Freq.- 50 Hz, 3 phase short circuit level at base voltage (VA)- 1000MVA, X/R ratio- 8

TWO LOADS: Nominal phase to phase Voltage- 25 kV, Configuration- Y (Grounded), Active power- 36 MW & 18 MW, reactive power- 10 MVAR and 5 MVAR, Freq. - 50 Hz

LINE: No. of phases- 3, Line length (km)- 30, Resistance per unit length (ohms/km)- [0.01755 0.2758], Inductance (H/km)- [0.8737x10-3 3.220x10-3], Capacitance (F/km)-[13.33x10-9 8.297x10-9], freq.- 50 Hz.

STATCOM parameters: 25 kV, ±100 MVAR, R =0.071, L =0.22, Vdc =1 kV, Cdc =750 μ F, Vref =1.0, Kp =5, Ki =1000, freq. = 50 Hz.

ULTC transformer parameter: 47 MVA, 120/25 kv, tap selection time = 4sec, Vref = 1 pu, min/max tap position = -8/+8, Voltage/tap = 0.018375 pu, freq. = 50 Hz.