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Modelling of Automated Controllable Network Transformer

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ABSTRACT:

Controllable Network Transformer (CNT) is considered as an important component in the AC links. It has flexibility of matching two networks of different voltage levels with subsequent power flow control. This work highlights the use of controllable network transformers along with simulation. The work further analysed CNT by automating its response to system voltage variation. The automation is successfully done using MATLAB simulation package. The output obtained proves beyond doubt the capability and indispensable nature of CNT in future trend of the network links.

KEYWORDS: *AC chopper, CNT, LTC, pulse width, tap.*

I. INTRODUCTION

Off-line optimal power flow and state estimation techniques are the conventional approaches used in the network operation. The dual constraints of the optimal power flow problem are the branch currents and the bus voltages. The output of the optimal power flow algorithm is used to set the operating points of various generators, shunt VAR compensation and Load Tap-Changing settings. In a highly interconnected meshed network, this represents a very challenging control problem. FACTS devices such as UPFC and SSSC provide control of both voltage magnitudes at a node, as well as phase angle. The angle control is instrumental in controlling branch currents. Shunt devices such as SVC's and STATCOM's provide the VAR regulation required to maintain the bus voltage levels in the network within acceptable range. Phase angle regulators provide power flow control. Its disadvantages are slow response and inability to control bus voltages. The Intelligent Universal Transformer [3] provides only unidirectional control of power flow and it is expensive. Power Electronics Transformer [4] has a high switch count and cost due to the high frequency transformer. The Sen Transformer [5] provides a solution for power flow control. Here, the interconnection between phases creates complex fault modes and high switch count is a limitation.

Controllable Network Transformer (CNT) is realised by augmentation of an existing load tap-changing (LTC) transformer with a small fractionally rated direct bidirectional ac chopper. CNT provides dynamic control of voltage magnitude and phase angle simultaneously over a meaningful control range. Also, CNT provides control of bus voltages and line currents in a meshed system which cannot be accomplished using conventional techniques. In this paper, modelling and automation of CNT is carried out using MATLAB.

II. POWER FLOW STUDY

Power flow studies, commonly known as load flow study, form an important part of power system analysis. They are necessary for planning, economic scheduling, and control of an existing system as well as planning its future expansion. The problem consists of determining the magnitudes and phase angle of voltages at each and active and reactive power flow in each line. In solving a power flow problem, the system is assumed to be operating under balanced conditions and a single-phase model is used.In order to make the load flow study as a simulation, representations are required for various components involved. The type of bus and the impedence connecting them forms the foremost requirement for any power system model. The general classifications of buses used in the system are as follows.

2.1.Bus Classification

A bus is a node at which one or many lines, one or many loads and generators are connected. In a power system each node or bus is associated with four quantities, such as magnitude of voltage $|V|$, phase angle of voltageδ, active or true power P and reactive power Q. In load flow problem, two out of these four quantities are specified and remaining two quantities are required to be determined through the solution of equation. Depending on the quantities that have been specified, the buses are classified into three categories. For load flow studies it is assumed that the loads are constant and they are defined by their real and reactive power consumption. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified.

2.2.Load buses. In these buses no generators are connected and hence the generated real power $P_{gi}$and reactive power $Q_{gi}$are taken as zero. The load drawn by these buses are defined by real power $-P_{li}$and reactive power $-Q_{li}$in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as P-Q bus. The objective of the load flow is to find the bus voltage magnitude $|V_i|$ and its angle δi.

2.3.Voltage controlled buses. These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant $P_{gi}$and $| V_i |$for these buses.

2.4.Slack or swing bus. Usually this bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as 0°. Furthermore it is assumed that the magnitude of the voltage of this bus is known.Using the bus voltage level and the admittance connecting them, power flow equations can be obtained. The solution of the equation is required for predicting power flow along various lines in the system. The typical power flow equation is discussed as follows.

2.5.Power flow equation: Consider a typical bus of a power system network as shown in the Figure 2.1. Transmission lines are represented by their equivalent π models where impedences have been converted to per unit admittances on a common MVA base.

Application of Kirchoff's Current Law to this bus results in:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \dots\dots + y_{in}(V_i - V_n)$$

$$= (y_{i0} + y_{i1} + y_{i2} + \dots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \dots\dots - y_{in}V_n \qquad (2.1)$$

The real power(P) and reactive power(Q) at bus 'i' is given by:

$$P_i + jQ = V_i I_i^* \qquad (2.2)$$

From the above relation, the mathematical forrmulation of the power flow problem results in a system of algebraic nonlinear equations which must be solved by iterative techniques.

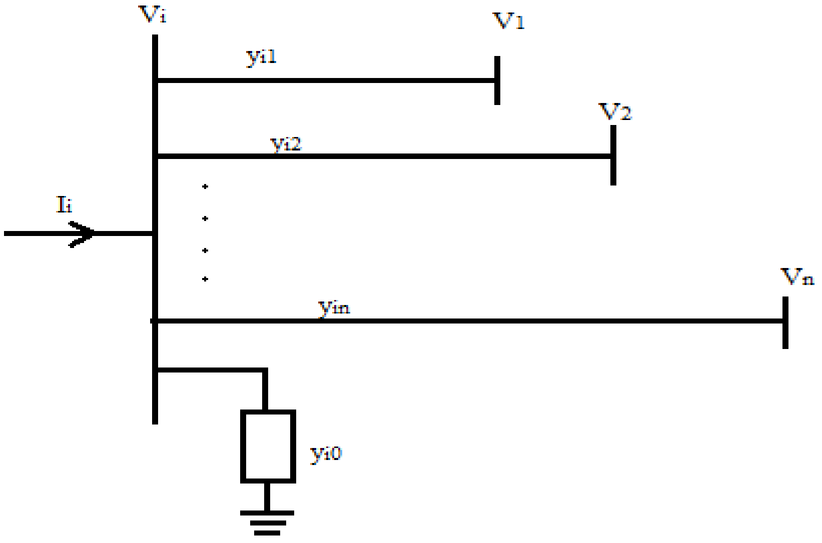

Figure 2.1 **A typical bus of the power system.**

Once the power flow across the system is determined, the adjustment at various levels can be obtained usually by voltage variations. Hence the tap changing transformer forms an integral and important part of the power system.

2.6.Tap changing transformers

Voltage variation in power systems is a normal phenomenon owing to the rapid growth of industries and distribution network. System voltage control is therefore essential for:

[1] Adjustment of consumers' terminal voltage within prescribed limits.
[2] Control of real and reactive power flow in the network.
[3] Periodical adjustment (1-10%) to check off-set load variations.

Adjustment is normally carried out by off-circuit tap changing, the common range being 5% in 2.5% steps. Daily and short-time control or adjustment is carried out by means of on-load tap changing gear. Besides the above, tapping are also provided for one of the following purposes:

[1] For varying the secondary voltage
[2] For maintaining the secondary voltage constant with a varying primary voltage.
[3] For providing an auxiliary secondary voltage for a special purpose, such as lighting.
[4] For providing a low voltage for starting rotating machines.
[5] For providing a neutral point,e.g. for earthing.

There are two types of tap-changing

[1] Off-load tap changing.
[2] On-load tap changing.

Off load tap changing transformer requires shut down of power for a while. Hence, on load tap changers are highly preferable in spite of disadvantages like losses etc.

2.7.Controllable network transformers

As an improvement, existing Load Tap Changing (LTC) transformer is augmented by a direct bidirectional AC chopper to give Controllable Network Transformer (CNT). The chopper consists of four IGBT/diode forming two ac switches (S1 and S2).The upper two IGBT/diode form S1and the lower two IGBT/diode form S2. A small capacitor, $C_f$and an inductor,$L_f$act as filters. A simple circuit of CNT is shown in the Figure 3.1.The two switches are operated by means of a pulse generator with fixed duty cycles. The switch S1 is operated at duty cycle D and the switch S2 at 1-D. When the switch S1 is ON, the turns ratio of the transformer is 1:(1+n), while when the switch S2 is ON, it becomes 1:(1-n). By applying fixed duty cycle D, it ispossible to control the output voltage magnitude between $1/1+n$and $1/1-n$per unit, where n is the tap ratio.

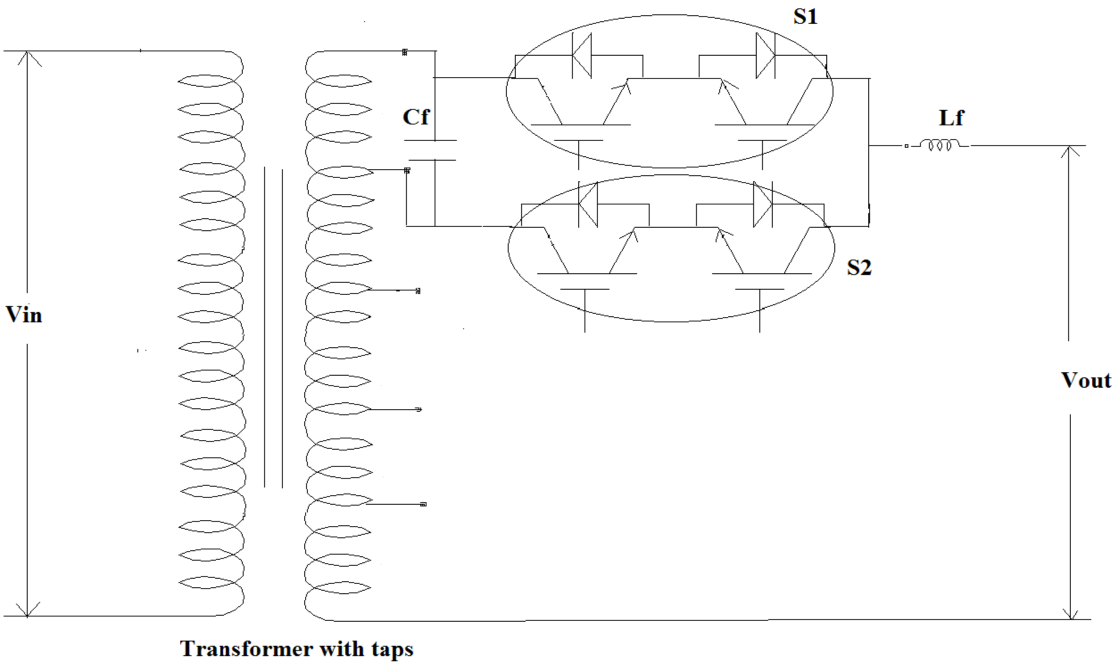

Figure 3.1**Controllable network transformer.**

If a small change in voltage level is needed, then the firing of IGBT is adjusted. If a major change in voltage level is required, then the tapings are changed according to the requirement.

IV. MODELLING AND AUTOMATION OF CNT

The modelling and simulation of CNT is done using circuit given in the Figure 4.1. The operating model of CNT is given by the block diagram as shown in the Figure 4.2.The block diagram consists of AC voltage source, multiwinding transformer, automatic tap selector subsystem, programmable pulse generator subsystem, multiport switches, AC chopper, and a resistive load.

4.1. Functions of CNT blocks

4.1.1 AC source. The input voltage to the multiwinding transformer is given by the AC voltage source.

4.1.2 Multiwinding Transformer. It is a transformer with multiple windings. The number of windings can be specified for the left side and for the right side of the block. Taps can be added to the upper left winding or to the upper right winding.

4.1.3 Multiport Switch. Multiport switch pass through the input signals corresponding to the truncated values of the first input. The inputs are numbered top to bottom. The first input port is the control port. The other input ports are data ports.

4.1.5 AC chopper. AC chopper converts the fixed alternating voltage to the variable alternating voltage.

4.1.6 Automatic tap and pulse width selector subsystem. The automatic tap selector subsystem provides information to choose the appropriate tap number for the voltage given at the subsystem input port.

4.1.7 Programmable pulse generator subsystem. This subsystem generates the triggering pulses applied to the gate of the IGBT switches of the AC chopper.

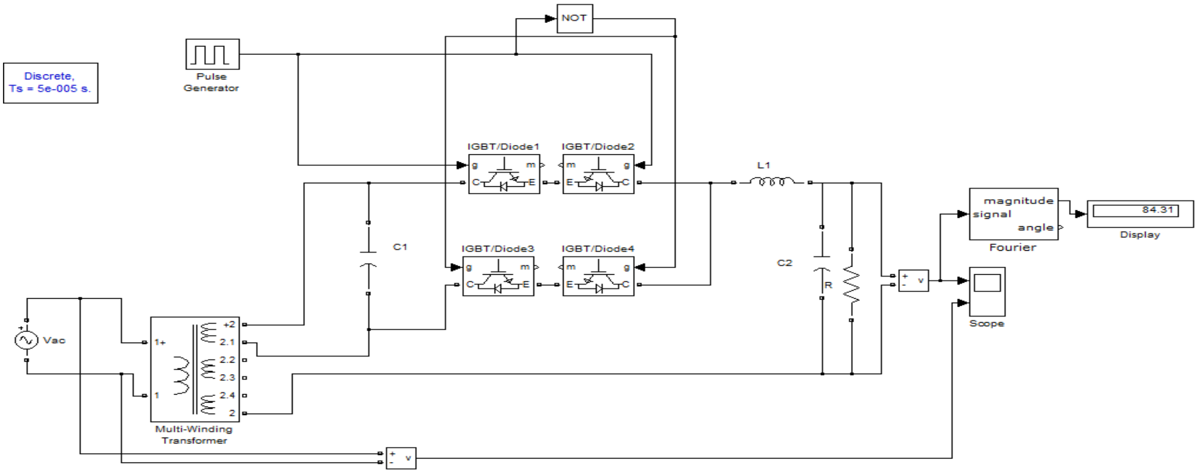

Figure 4.1 **Simulation model of CNT.**

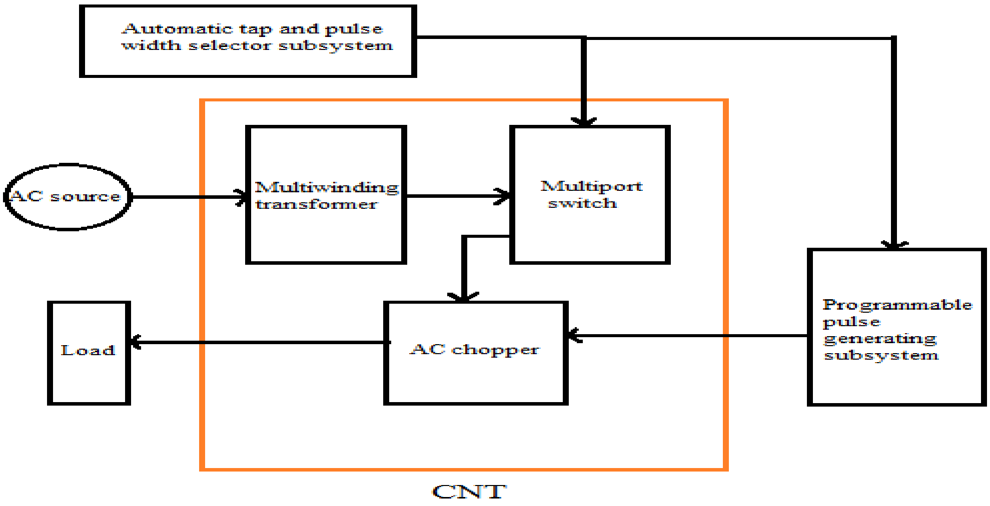

Figure 4.2 **Block diagram of the CNT model**

4.2. Operation of CNT

A model of CNT is simulated with a multiwinding transformer of rating 230/100V with five tapping on secondary. At first, the chopper is connected between the uppermost tap and the next tap as shown in the Figure 4.1.This arrangement makes the chopper to be connected between 100 and 80 volts. The IGBT switches of the chopper are triggered using pulse generator. The upper two IGBTs of the chopper are given duty cycle D and the lower two IGBTs are given duty cycle 1-D. By varying the pulse width applied to the gates of the IGBT switches, the voltage at the output of the chopper can be varied between 100 and 80 volts. Simulation of the CNT model is carried out for different pulse width and the corresponding voltage at the output are taken.

Next, the chopper is connected between 80 and 60 volts and simulated for different pulse width. The corresponding output voltages are noted. Then, the chopper is connected between 60 and 40 volts. Finally, the chopper is connected between 40 and 20 volts. The model is simulated for various values of pulse width and the corresponding output voltages are taken and tabulated as shown in the Table 4.1. The various elements and operation are discussed as follows.

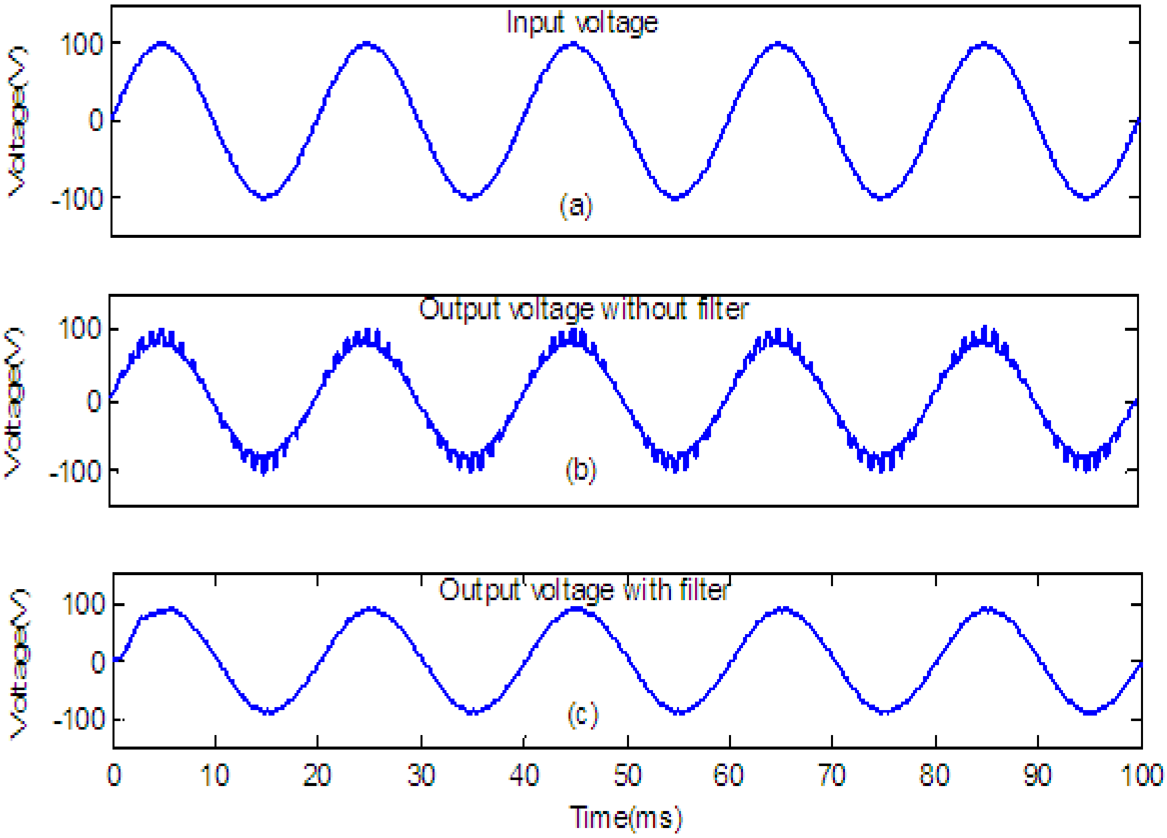

Figure 4.3. **Waveforms of AC chopper. (a) input voltage, (b)output voltage without filter, (c)output voltage with filter.**

4.2.1. AC chopper. AC chopper is a type of AC-AC Converter. The input voltage is chopped into segments and the output voltage level is decided by controlling the duty cycle of the chopper switches. The mean output voltage over one switching cycle is proportional to the duty cycle in that period. If V_{in} is the input voltage and V_{out} is the output voltage, they are related by the formula as follows: $V_{out} = \alpha . V_{in}$, where α is the duty cycle.

The waveforms of input voltage, output voltage without filter, output voltage with filter for thirty percentage of the duty cycle when the chopper is connected between 100 and 80 volts is shown in the Figure 4.3.

4.2.2. Automatic Tap and Pulse Width selector subsystem. The tap selection and pulse width selection is evaluated priory for various voltage levels and tabulated as given in the Table 4.1. The table is used for the simulation in the MATLAB. When an input of required voltage is given, the lookup table, which contains the previously evaluated table will give tap and pulse width with interpolation if required. The Simulation model of this subsystem is shown in the Figure 4.4.

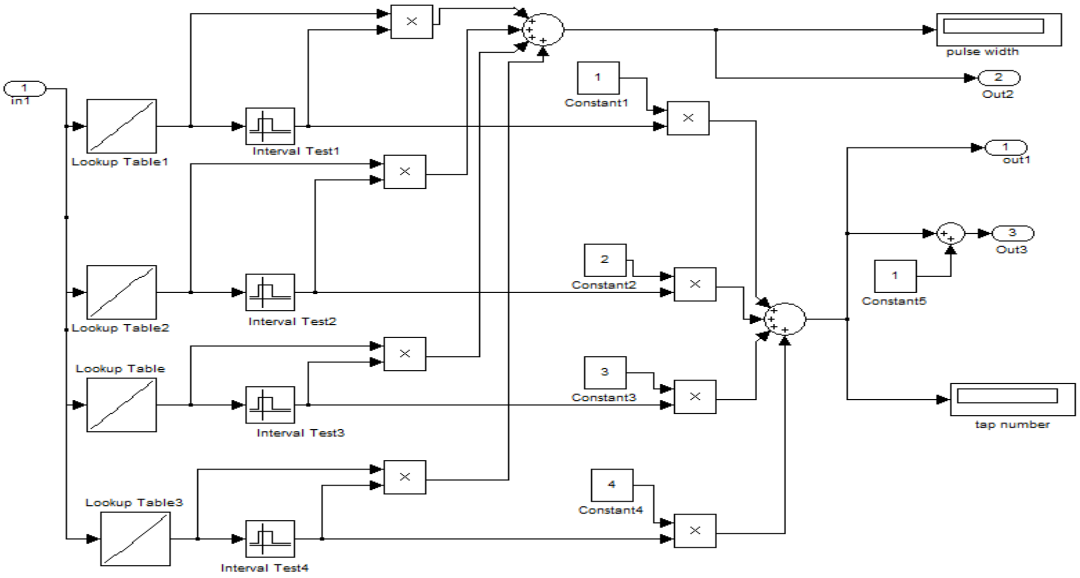

Figure 4.4. **Simulation model of automatic tap and pulse width selector subsystem.**

4.2.3. Programmable Pulse generator subsystem. Programmable pulse generating subsystem will obtain the pulse width output as described in the section 4.2.2 and produces pulse for triggering the corresponding chopper. Thus the integrated system acts as an automated CNT.In order to explain the operation of the automated CNT, an example is given in which the voltage required by the system is 65 volts. This voltage data is fed to the inport of the automatic tap and pulse width selector subsystem. All the four lookup tables in the subsystem get this data at their inputs. The lookup tables contain information of pulse width for the required voltage. After the pulse width information, taps selection is done based on relevant output. Hence, tap positions of number 2 and 3 are selected with pulse width of 20 percentage of the duty cycle. In this way, the chopper outputs the same voltage (65 volts) required by the system.

Table 4.1. **Pulse width vs. voltage magnitude for different taps**.

Pulsewidth (percentage of time period)	**Voltage magnitude**			
	Between taps 2 & 2.1	**Between taps 2.1 & 2.2**	**Between taps 2.2 & 2.3**	**Between taps 2.3 & 2.4**
10	84	63	43	22
20	86	65	45	24
30	88	67	47	27
40	90	69	49	29
50	92	71	51	31
60	94	73	53	33
70	96	75	55	35
80	98	78	57	37
90	100	80	59	39

V. Conclusion

The simulation of Controllable Network Transformer and its automation is successfully done by using the MATLAB simulations.CNT is considered as the important component and has flexibility of matching two networks of different voltage levelsPower flow through the tie-lines connecting two control areas can be controlled by controlling the output voltage magnitude by using CNT. The output proves the capability and indispensable nature of the CNT in the future power grids.

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