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ENHANCED LOADABILITY OF EXISTING EHVAC LINE BY COMBINED AC-DC TRANSMISSION SYSTEM

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Abstract: Now-a-days, demand for electric power has shown steady but geographically uneven growth.The wheeling of the available energy through existing long ac lines to load centers has a certain upper limit due to stability considerations. Thermal limit is the major limit to be considered while increasing loadability of existing EHV long transmission lines. Thus, these lines cannot be loaded to their thermal limit to keep sufficient margin against transient instability.

This paper presents the concept of composite ac-dc power transmission. The conductors are allowed to carry usual ac along with dc superimposed on it. This will load the transmission lines close to its thermal limit thereby increasing the stability of the system. This paper presents the feasibility of converting a double circuit ac line into composite ac–dc power transmission line to get the advantages of parallel ac–dc transmission to improve stability and damping out oscillations. No alterations of conductors, insulator strings, and towers of the original line are needed. The proposed scheme is digitally simulated with the help of MATLAB software package. Simulation results clearly indicate the substantial increase in loadability of existing EHV AC lines by combined ac-dc transmission.

Keywords: Extra high voltage (EHV) transmission, MATLAB simulation, simultaneous ac-dc transmission

I. INTRODUCTION

In recent years, environmental, right-of-way, and cost concerns have delayed the construction of a new transmission line, while demand of electric power has shown steady but geographically uneven growth. The power is often available at locations not close to the growing load centers but at remote locations. These locations are largely determined by regulatory policies, environmental acceptability, and the cost of available energy. The wheeling of this available energy through existing long ac lines to load centers has a certain upper limit due to stability considerations. Thus, these lines are not loaded to their thermal limit to keep sufficient margin against transient instability.

The present situation demands the review of traditional power transmission theory and practice, on the basis of new concepts that allow full utilization of existing transmission facilities without decreasing system availability and security. Long extra high voltage (EHV) ac lines cannot be loaded to their thermal limits in order to keep sufficient margin against transient instability. With the scheme proposed in this paper, it is possible to load these lines very close to their thermal limits. The conductors are allowed to carry usual ac along with dc superimposed on it. The added dc power flow does not cause any transient instability. In this paper, the feasibility study of conversion of a double circuit ac line to composite ac–dc line without altering the original line conductors, tower structures, and insulator strings has been presented.

II.COMBINED AC-DC TRANSMISSION

Fig.1 depicts the basic scheme for simultaneous AC-DC power flow through a double circuit AC transmission line. The double circuit AC transmission line carriers both three-phase AC and DC power. The DC power is obtained through line commutated 12-pulse rectifier bridge used in conventional HVDC and injected to the neutral point of the zigzag connected secondary of sending end transformer and is reconverted to ac again by the conventional line commutated 12-pulse bridge inverter at the receiving end. The inverter bridge is again connected to the neutral of zig-zag connected winding of the receiving end transformer.

The double circuit AC transmission line carriers both three-phase AC and DC power. Each conductor of each line carriesc one third of the total DC current along with AC current. Resistance being equal in all the three phases of secondary winding of zig-zag transformer as well as the three conductors of the line, the DC current is equally divided among all the three phases.

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The three conductors of the second line provide return path for the DC current. Zig-zag connected winding is used at both ends to avoid saturation of transformer due to dc current. Two fluxes produced by the dc current $I_d/3$ flowing through each of a winding in each limb of the

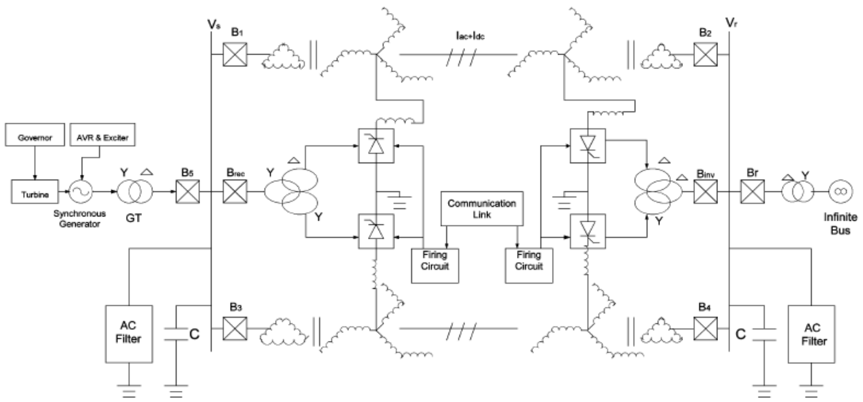

Fig. 1 Single line diagram for composite AC–DC transmission

core of a zig-zag transformer are equal in magnitude and opposite in direction. So the net DC flux at any instant of time becomes zero in each limb of the core. Thus, the DC saturation of the core is avoided. A high value of reactor X_d is used to reduce harmonics in DC current. In the absence of zero sequence and third harmonics or its multiple harmonic voltages, under normal operating conditions, the AC current flow through each transmission line will be restricted between the zigzag connected windings and the three conductors of the transmission line. Even the presence of these components of voltages may only be able to produce negligible current through the ground due to high value of X_d Assuming the usual constant current control of rectifier and constant extinction angle control of inverter, the equivalent circuit of the scheme under normal steady-state operating condition is given in Fig.2. The dotted lines in the figure show the path of ac return current only. The second transmission line carries the return DC current, and each conductor of the line carries $I_d/3$ along with the AC current per phase. and are the maximum values of rectifier and inverter side DC voltages and are equal to $3\sqrt{2}/\pi$ times converter AC input line-to-line voltage. R, L, and C are the line parameters per phase of each line. , R_{cr}, R_{ci} are commutating resistances, and $\alpha,$ firing angle of rectifier and inverter.

III. MASTER CURRENT CONTROLLER

I_a being the rms ac current per conductor at any point of the line, the total rms current per conductor becomes

$$I = [I_a^2 + (I_d/3)^2]^{1/2} \text{ and } P_L = 3I^2R$$

The net current I in any conductor is offseted from zero.

Now allowing the net current through the conductor equal to its thermal limit(I_{th})

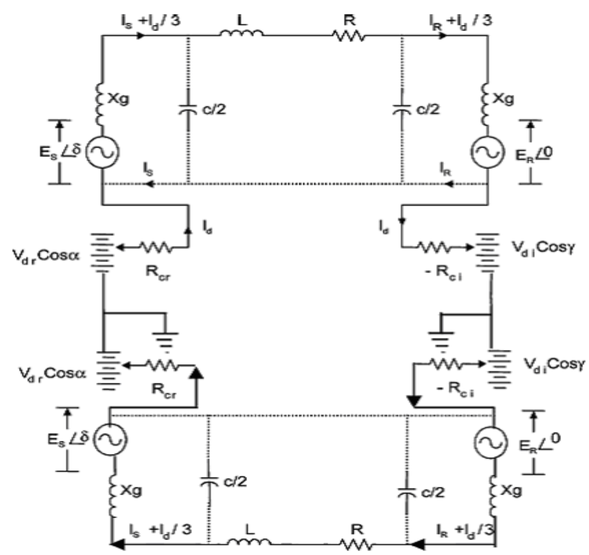

Fig. 2 Equivalent circuit for normal steady-state operating condition

$$I_{th} = [I_a^2 + (I_d/3)^2]^{1/2}$$

The on-line dc current order for rectifier is adjusted as

$$I_d = 3\,[I_{th}^2 - I_a^2]^{1/2}$$

A master current controller (MCC), shown in Fig. 3 is used to control the current order for converters.It measures the conductor ac current, computes the permissible dc current, and produces dc current order for inverters and rectifiers

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IV. SYSTEM UNDER STUDY

A synchronous machine is feeding power to infinite bus via a double circuit, three-phase, 400- KV, 50-Hz, 450-Km AC transmission line.

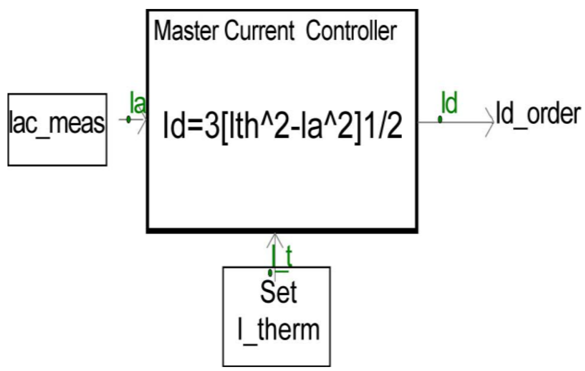

Fig.3 Master current controller

The 2750-MVA (5 *550), 24.0-KV synchronous machine is dynamically modeled, a field coil on d-axis and a damper coil on q-axis, by Park's equations with the frame of reference based in rotor.

Transmission lines are represented as the Bergeron model .It is based on a distributed LC parameter traveling wave line model, with lumped resistance. It represents the L and C elements of a PI section in a distributed manner (i.e., it does not use lumped parameters).

It is roughly equivalent to using an infinite number of Proportional Integral(PI) sections, except that the resistance is lumped (1/2 in the middle of the line, 1/4 at each end). Like PI sections, the Bergeron model accurately represents the fundamental frequency only. It also represents impedances at other frequencies, except that the losses do not change. This model is suitable for studies where the fundamental frequency load flow is most important.

The converters on each end of DC link are modeled as line commutated two six- pulse bridge (12-pulse), Their control system consist of constant current (CC) and constant extinction angle (CEA) and voltage dependent current order limiters (VDCOL) control. The converters are connected to AC buses via Y-Y and Y- converter transformers. Each bridge is a compact power system computer-aided design (SIMULINK) representation of a DC converter, which includes a built in six-pulse Graetz converter bridge (can be inverter or rectifier), an internal phase locked oscillator (PLO), firing and valve blocking controls, and firing angle /extinction (α) angle (γ) measurements. It also includes built in RC snubber circuits for each thyristor. The controls used in DC system are those of CIGRE Benchmark, modified to suit at desired DC voltage. AC filters at each end on AC sides of converter transformers are connected to filter out 11th and 13th harmonics.DC filters at each end on Dc sides of the transformer are connected to filter out harmonics. These filters and shunt capacitor supply reactive power requirements of converters.

V.COMPUTED RESULTS OF THE PROPOSED SCHEME

Case A: AC Configuaration only

The laudability of Moose (commercial name), ACSR, twin bundle conductor, 400-kV, 50-Hz, 450-km double circuit line has been computed.

The parameters of the line are

$z=0.03252+j0.33086$ ohm/km/ph/ckt

$y=j3.3379*10^{-6}$ S/km/ph/ckt

Current carrying capacity of each conductor=0.9 kA

I_{th} =1.8 kA/ckt, SIL=511 MW/ckt

x=74.4435 ohms/ph

Current carrying capacity of each conductor=0.9 kA

I_{th} =1.8 kA/ckt, SIL=511 MW/ckt

M=1.1 from load ability curve; X=74.4435 ohms/ph

Calculation for 30^0:

Let V_{ph} be per-phase rms voltage of original double circuit 400kV(L-L) AC line,

$$V_{ph}= 400/\sqrt{3} = 230.94 \text{ kV}$$

AC current per phase per circuit of the original double circuit line is computed as

$$I_{ph}/ckt = V_{ph} (\sin \delta_1/ 2)/X = \mathbf{0.803kA}$$

Where δ_1 is the power angle between the voltages at the two ends.

The total power transfer through the double circuit line before conversion

$$P'_{total}= \frac{3V_{ph}^2 \sin\delta_1}{X} = \mathbf{1074.64MW}$$

Case B:Conversion of the Conventional Double Circuit AC line into Composite AC-DC Power Transmission line

Let V_{ph} be per-phase rms voltage of original AC line. Let also V_a the per-phase voltage of AC component of composite AC-DC line with DC voltage V_d superimposed on it. As insulators remain unchanged, the peak voltage in both cases should be equal.

Case B:Conversion of the Conventional Double Circuit AC line into Composite AC-DC Power Transmission line

Let V_{ph} be per-phase rms voltage of original AC line. Let also V_a the per-phase voltage of AC component of composite AC-DC line with DC voltage V_d superimposed on it. As insulators remain unchanged, the peak voltage in both cases should be equal in a cycle if $(V_d/V_a) < \sqrt{2}$ is insured. Therefore, higher creepage distance requirement for insulator discs used for HVDC lines are not required. Each conductor is to be insulated for,V_{max} but the line-to line voltage has no DC component and $V_{LLmax} = \sqrt{6}V_a$. Therefore, conductor-to-conductor separation distance of

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each line is determined only by rated AC voltage of the line. Allowing maximum permissible voltage offset such that the composite voltage wave just touches zero in each every cycle;

$V_d = V_{ph}/\sqrt{2}$ and $V_a = V_{ph}/2$

Using (5.1) & (5.2),we get

V_a = 120 KV/ph (208kV_{LL} ; V_d = 160 kV.

The above ac voltage Va has been increased from 115.473 to 120 kV, and Vd has been decreased from 163.328 to 160.0 kV to have zero crossing in voltage wave.

TABLE I
Computed values for total power transfer in composite ac-dc line

Power Angle (δ) Degrees	**30°**	**45°**	**60°**	**75°**	**80°**
ac power (MW) $=3V_a^2 Sin\delta_2/X$	290	410	502.61	560.6	571.55
Ac current $I_a=V(\sin \delta/2)/X$	0.4166	0.6122	0.805	0.98	1.035
dc Current(kA) $I_d=3\sqrt{(I_{th}^2-I_d^2)}$	5.253	5.078	4.829	4.529	4.418
Dc Power P_{dc}=2Vdi x Idi(MW)	1684.8	1624.9	1545.5	1149.44	1413.76
$P_{total}=P_{ac}+P_{dc}$ (MW)	1971	2034	2048	2010	1985

V. DIGITAL SIMULATION OF THE PROPOSED SCHEME

In order to examine the feasibility of the proposed scheme for enhanced power transfer and to observe the performance of the composite ac-dc power transmission system under various operating conditions, the MATLAB simulation is used. The simulated results in steady state are shown in Figs

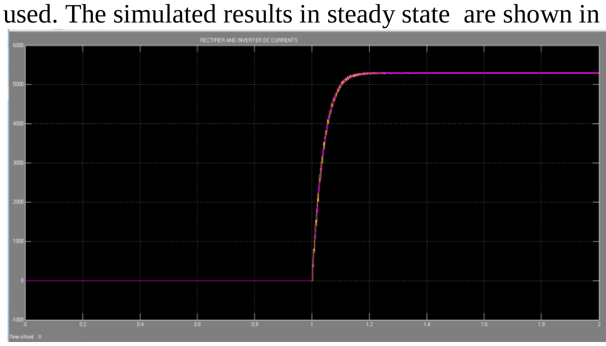

Fig. 4 Rectifier and Inverter DC currents

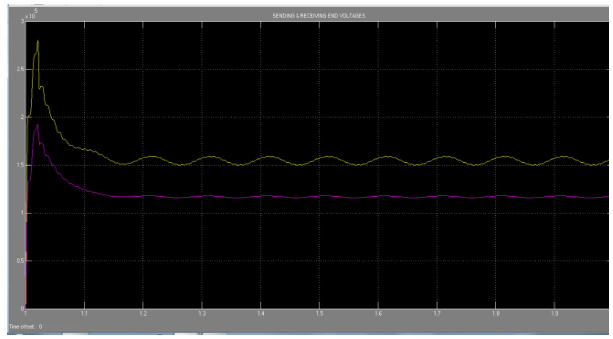

Fig.5 Sending & receiving end voltages.

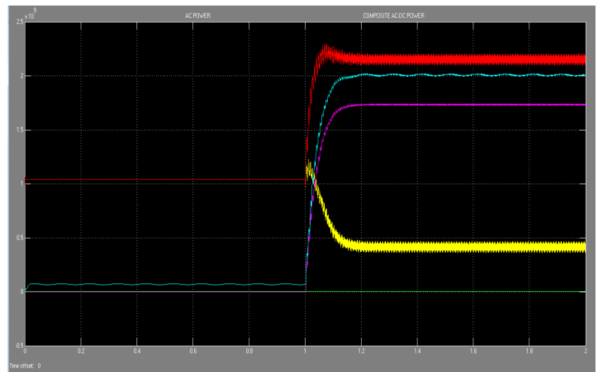

Fig. 6 Sending end (Ps), ac (Pac), dc(Pdc), and total transfer (Ptotal_tr) power

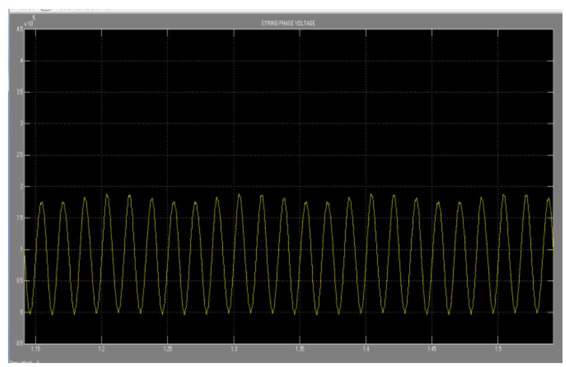

Fig. 7 String phase voltage

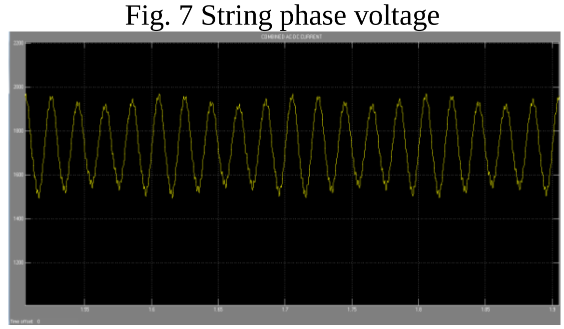

Fig. 8. Combined AC-DC Current ($I_{ac\text{-}dc}$=1.785kA)

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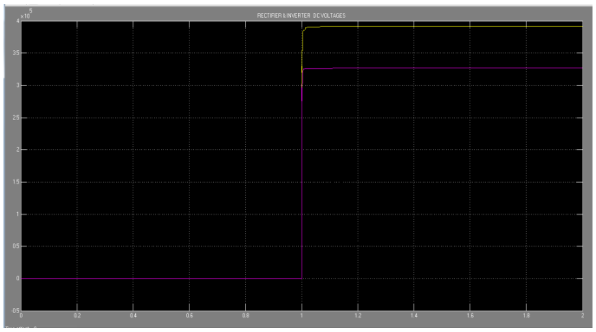

Fig .9 Converter voltages (V_{dcr}=375kV;V_{dci}=325kV)

The above simulated results clearly demonstrate that there is substantial increase in the loadability of the line if converted to a composite ac-dc line. The line is loaded to its thermal limit with the superimposed dc current

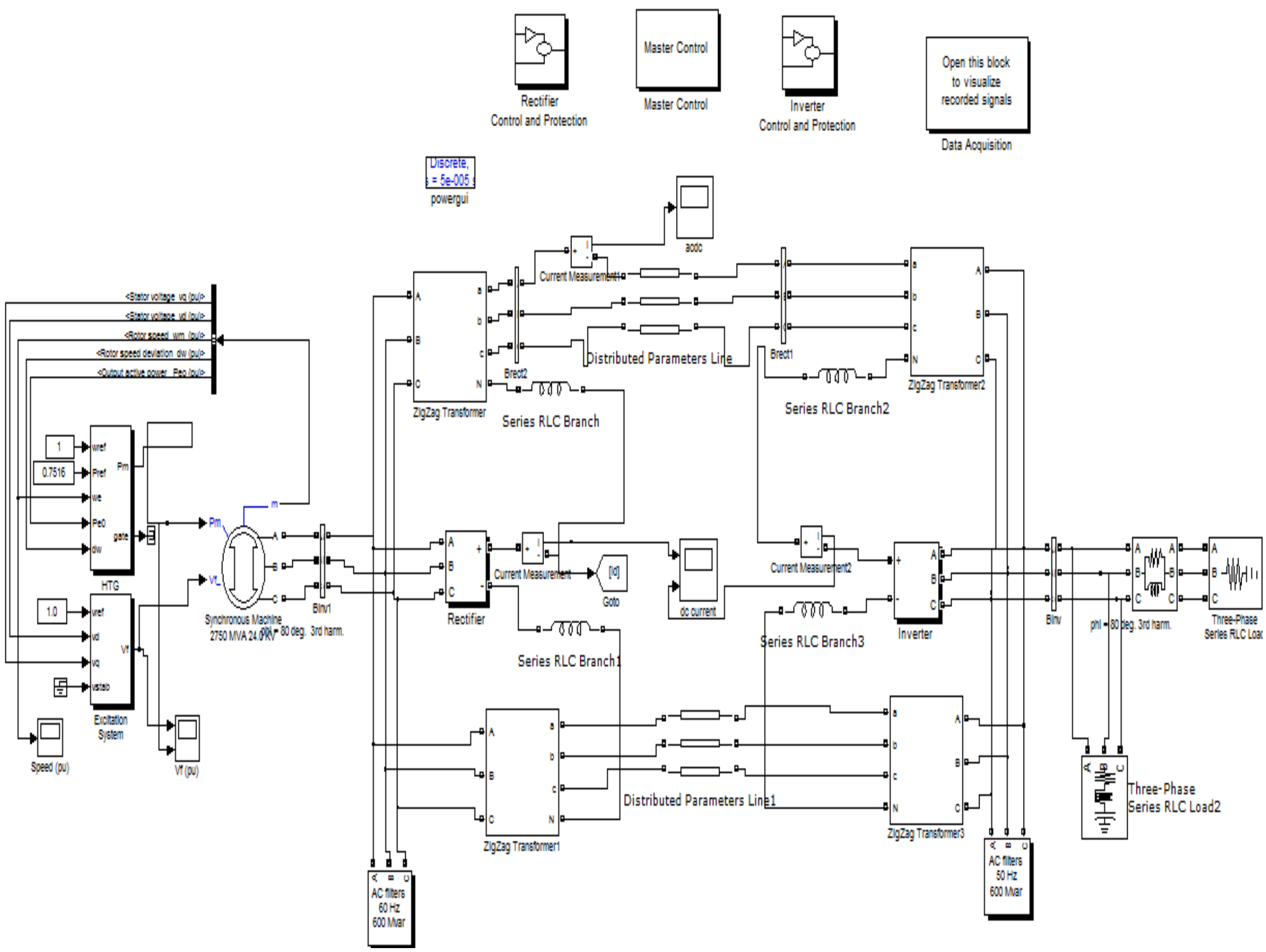

Fig. 10 Simulink block diagram for simultaneous ac-dc transmission system

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VII. COMPARISON OF RESULTS

AC CONFIGURATION ONLY

TABLE.2
Simulation results of ac configuration

POWER ANGLE, δ	30°
LINE LENGTH	450kms
AC CURRENT , I_{ac}	0.76kA
AC VOLTAGE, V_{ph}	230kV
POWER TRANSFER, P'_{total}	**1090MW**

COMPOSITE AC-DC CONFIGURATION

TABLE.3
Simulation results of composite ac-dc configuration

POWER ANGLE, δ	30°
LINE LENGTH	450kms
AC CURRENT, I_a	400A
DC CURRENT, I_d	5.3kA
CONDUCTOR DC CURRENT, $I_d/3$	1.740kA
CONDUCTOR CURRENT, $I_{ac\text{-}dc}$	1.785kA
AC VOLTAGE, V_a	120kV
DC VOLTAGE,V_d	160kV
AC POWER, P_{ac}	300MW
DC POWER, P_{dc}	1735MW
TOTAL POWER TRANSFER, $P_{ac\text{-}dc}$	**1935MW**

Thus there is substantial increase (about 77.52%) in the loadability of the line if converted to a composite ac-dc line. The line is loaded to its thermal limit with the superimposed dc current. It has been verified from computation as well as simulation that the maximum power transfer of 2062MW transmitted by composite ac-dc line occurs at power angle of 60°. The same amount of power transfer through conventional double circuit line would require a power angle of 73.68°, which is beyond the safe limit for power angle. The corresponding conductor current is 1.7744 kA. It has been observed from above tracing that system is stable even after superimposing dc on ac.

IV. VIII CONCLUSION

The feasibility to convert ac transmission line to a composite ac–dc line has been demonstrated. For the particular system studied, there is substantial increase (about 83.45%) in the loadabilty of the line. The line is loaded to its thermal limit with the superimposed dc current. The dc power flow does not impose any stability problem. The advantage of parallel ac–dc transmission is obtained. Dc current regulator may modulate ac power flow. There is no need for any modification in the size of conductors, insulator strings, and towers structure of the optimum values of ac and dc voltage components of the converted composite line are 1/2 and $1/\sqrt{2}$ times the ac voltage

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