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Research Paper

POWER UPGRADATION AND POSSIBILITY OF SMALL POWER TAPPING FROM COMPOSITE AC-DC TRANSMISSION SYSTEM

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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 wheeling of the available energy through existing long ac lines to load centers has a certain upper limit due to stability considerations. 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 paper also presents the feasibility of small power tapping from composite ac-dc power transmission lines which would pass over relatively small communities/rural areas having no access to a major power transmission network. It is economical compared to complicated methods of tapping from the HVDC line. The proposed scheme is digitally simulated with the help of MATLAB software package. Simulation results clearly indicate that the tapping of a small amount of ac power from the composite ac-dc transmission line has a negligible impact on the normal functioning of the composite ac-dc power transmission system.

Keywords: Extra High Voltage (EHV) transmission, Flexible AC Transmission System (FACTS), MATLAB simulation, simultaneous ac-dc transmission, small power tapping

INTRODUCTION

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.

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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.

Presently, about half of the world's population, especially those in developing countries, live without electricity. These days, the supply of electricity is considered essential to avail normal facilities of daily life. Its availability is fundamental for economic development and social upliftment. Large power (steam, hydro, nuclear) stations are usually located far from load centers. The wheeling of this available electric energy from these remotely located stations to load centers is achieved either with extra high-voltage (EHV) ac or HVDC transmission lines. These EHV ac/HVDC transmission lines often pass over relatively small communities/rural areas that do not have access to a major power transmission network. It is most desirable to find methods for connecting these communities to the main transmission system to supply cheap and abundant electrical energy. However, the HVDC transmission system does suffer a significant disadvantage compared to EHV ac transmission, in regards to the tapping of power from a transmission system.

Techno-economical reasons prevent the tapping of a small amount of power from HVDC transmission lines. This is considered a major drawback due to the fact that in many instances, HVDC transmission lines pass over many rural communities that have little or no access to electricity.

From this composite ac-dc line, small power tapping is also possible despite the presence of a dc component in it. This paper proposes a simple scheme of small power tapping from the composite ac-dc power transmission line along its route. In this study, the tapping stations are assumed to draw power up to 10% of the total power transfer capability of the composite line. However, more power tapping is also possible subject to the condition that it is always less than the ac power component.

REQUIREMENTS OF A SMALL POWER TAPPING STATION

The main requirements of a small power tapping stations are as follows.

- The per unit cost of the tap must be strongly constrained (i.e., the fixed cost must be kept as low as possible).
- The tap must have a negligible impact on the reliability of the ac–dc system. This implies that any fault in the tap must not be able to shutdown the whole system.
- The tap controls should not interfere with the main system (i.e., the tap control system has to be strictly local). Failure to achieve this leads to a complex control system requirement and, thus, higher cost of hardware.
- Small tap stations having a total rating less than 10% of the main terminal rating have potential applications where small, remote communities or industries require economic electric power.

MODELLING DETAILS OF SYSTEM UNDER STUDY

The network depicted in Figure 1 has been taken up for the feasibility of a small power tap for remote communities from the composite ac-dc power transmission system. The details of power tap substations are shown in Figure 2. A synchronous machine is delivering power to an infinite bus via a double-circuit 400 kV, 50 Hz, 450 km ac transmission line. The minimum value of ac phase voltage and maximum value of dc voltage with respect to ground of the converted composite ac–dc line, respectively, are 1/2 and 1/√2 times that of per phase voltage before conversion of the conventional pure EHV ac line. The line considered is converted to a composite ac-dc transmission line with an ac rated voltage of 220 kV and a dc voltage of 320 kV. In a composite ac-dc transmission line, the dc component is obtained by converting a part of the ac through a line-commutated 12-pulse rectifier bridge similar to that used in a conventional HVDC. The dc current thus obtained is injected into the neutral point of the zig-zag-connected secondary windings of sending end transformer. The injected current is distributed equally among the three windings of the transformer. The same is reconverted to ac by the conventional line commutated inverter at the receiving end. The inverter bridge is connected to the neutral of zig-zag-connected winding of the receiving end transformer. The transmission line is connected between the terminals of the zig-zag windings at both ends. The double-circuit transmission line carries both three-phase ac as well as dc power after conversion to a composite ac-dc line.

Figure 1: Single-Line Diagram of Basic Composite ac-dc Transmission System

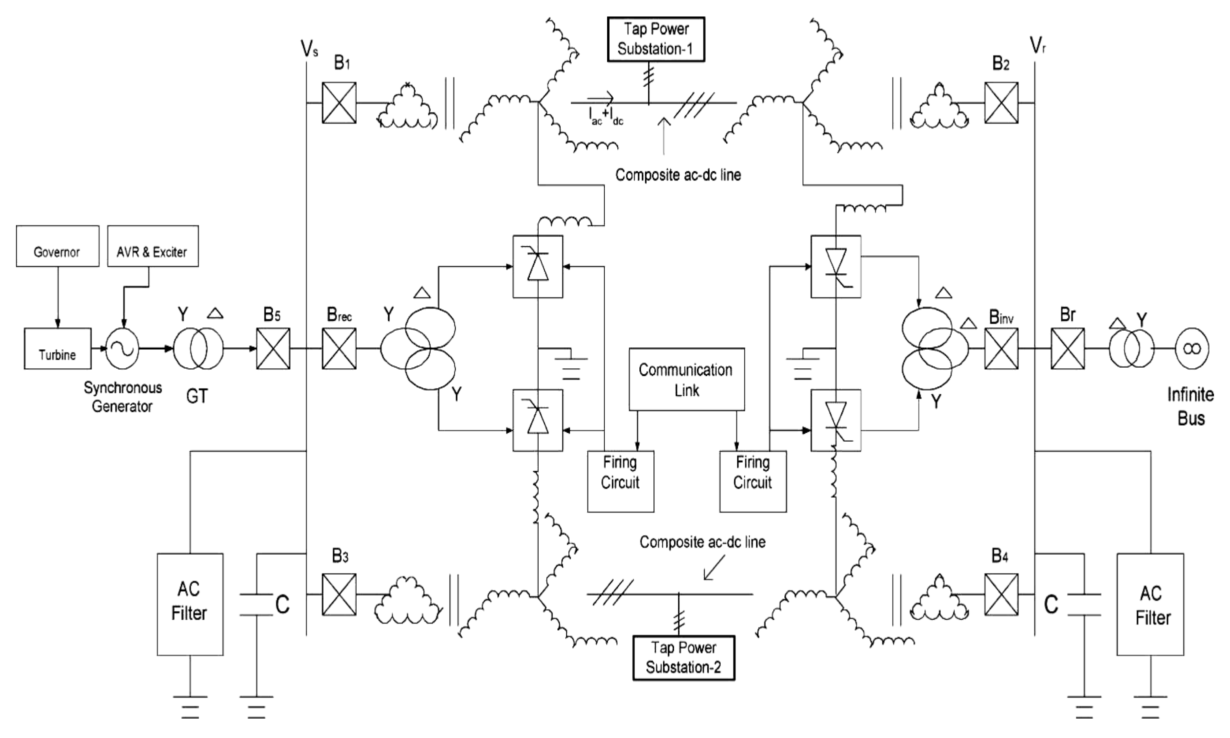
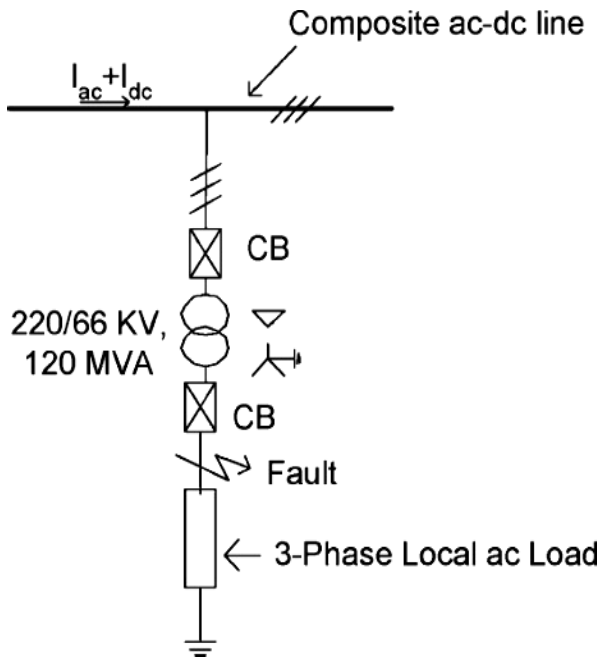


Figure 2: Single-Line Diagram of Power Tap Substation



The zig-zag connection of secondary windings of the transformer is used at both ends to avoid saturation of the core due to the flow of the dc component of current. The replacement of a Y-connected transformer from a conventional EHV ac line with a zig-zag transformer in composite ac-dc power transmission is accomplished along with the reduction of ac voltage in such a way that the insulation-level requirements remain unaltered. However, the neutral point of this transformer needs insulation to withstand the dc voltage. Moreover, the zig-zag transformer transfers only 25% of the total power by transformer action.

In this study of a composite ac-dc transmission line, the ac-line voltage component has been selected as 220 kV. Each tapping station transformer (rated as 120 MVA, 220/66 KV, Δ-Y) is connected to the local ac load via a Circuit Breaker (CB) as depicted in Figure 2. These CBs are provided for local protection, to clear the fault within the local ac network.

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})

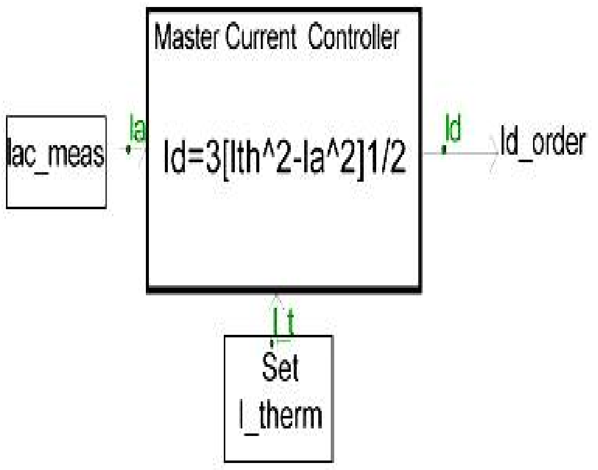
$$I_{th} = [I_a^2 + (I_d/3)^2]^{1/2}$$

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 Figure 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.

Figure 3: Master Current Controller



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.

AC Configuration 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

Table 1: Computed Results

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) $I_d = 3\surd(I_{th}^2 - I_d^2)$	5.253	5.078	4.829	4.529	4.418
Dc Power $P_{dc} = 2Vdi \times Idi$ (MW)	1684.8	1624.9	1545.5	1149.44	1413.76
$P_{total} = P_{ac} + P_{dc}$ (MW)	1971	2034	2048	2010	1985

Table 2: Simulation Results

Power Angle (δ)	**30°**	**45°**	**60°**	75°	**80°**
Ps (MW)	2306	2371.0	2381.3	2342.0	2318.380
Pac (MW) Transfer	294.89	411.00	495.3	541.86	548.43
Pdc (MW)	1715.5	1657.0	1585.8	1498.5	1467.0
Pac_loss (MW)	11.94	30.30	54.08	81.94	91.73
Pdc_loss (MW)	280.51	265.88	241.17	217.61	208.53
Ploss_total (MW)	292.45	296.18	295.25	299.25	300.26
Pr (MW) Total Transfer	1988.8	2051.14	2062.0	2019.36	1995.00
Qs_line (MVAR)	–13.78	69.98	185.58	325.12	375.35
Qr_line (MVR)	39.08	146.84	280.85	431.96	484.38
Qrec (MVAR)	883.6	884.36	885.29	878.1	869.48
Qinv (MVAR)	841.3	832.5	797.43	764.64	753.04
ac Current Ia (kA)	0.42577	0.61123	0.79684	0.96952	1.02383
Dc Current Id (kA)	5.24263	5.1136	4.91183	4.6335	4.52512
Cond. dc Current Id/3 (kA)	1.74754	1.70453	1.6373	1.5452	1.5084
Conductor Current Isim (kA)	1.78587	1.78264	1.78281	1.78641	1.78833
Increase of Power Transfer	76.94%	82.49%	83.451%	79.66%	77.5%

Figure 4: Rectifier and Inverter DC Currents

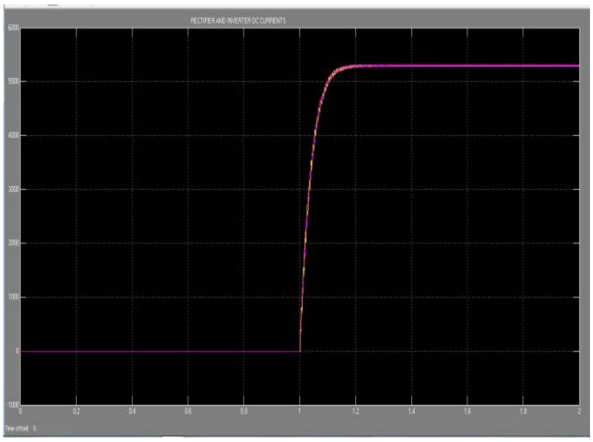


Figure 5: Sending and Receiving End Voltages

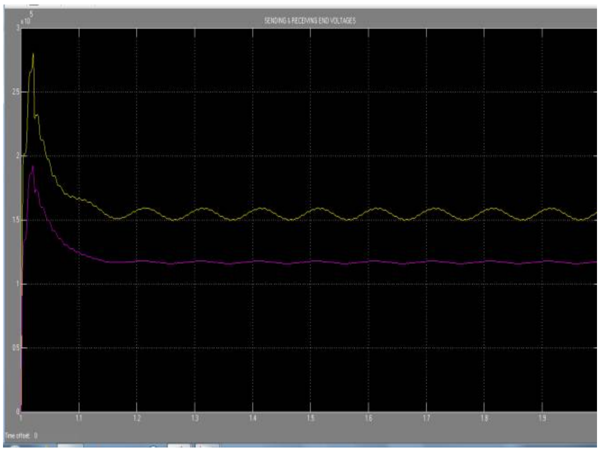
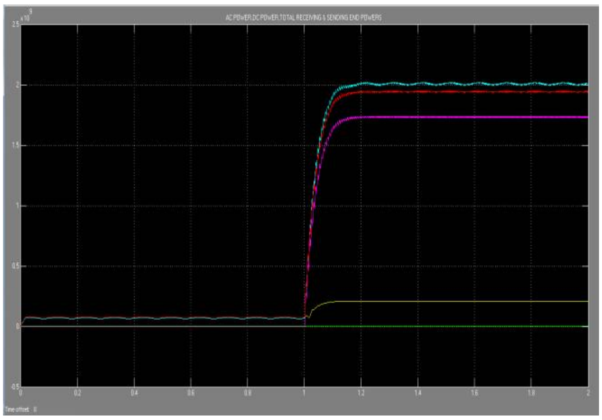


Figure 6: Sending End (Ps), ac (Pac), dc (Pdc), and Total Transfer (Ptotal_tr) Power



The simulated results in steady state are shown in Figures 4-6.

SMALL POWER TAPPING

In order to examine the feasibility of the proposed scheme for power tapping under various operating conditions, the digital simulation software package was used. The initial operating conditions of the simultaneous ac-dc power transmission system before the tapping power is switched on are the following:

Table 3: Initial Operating Conditions Before Tapping

P_{ac}	603.735 MW
P_{dc}	1560.183 MW
$P_{total\_transfer}$	2162.9 MW
δ	60°

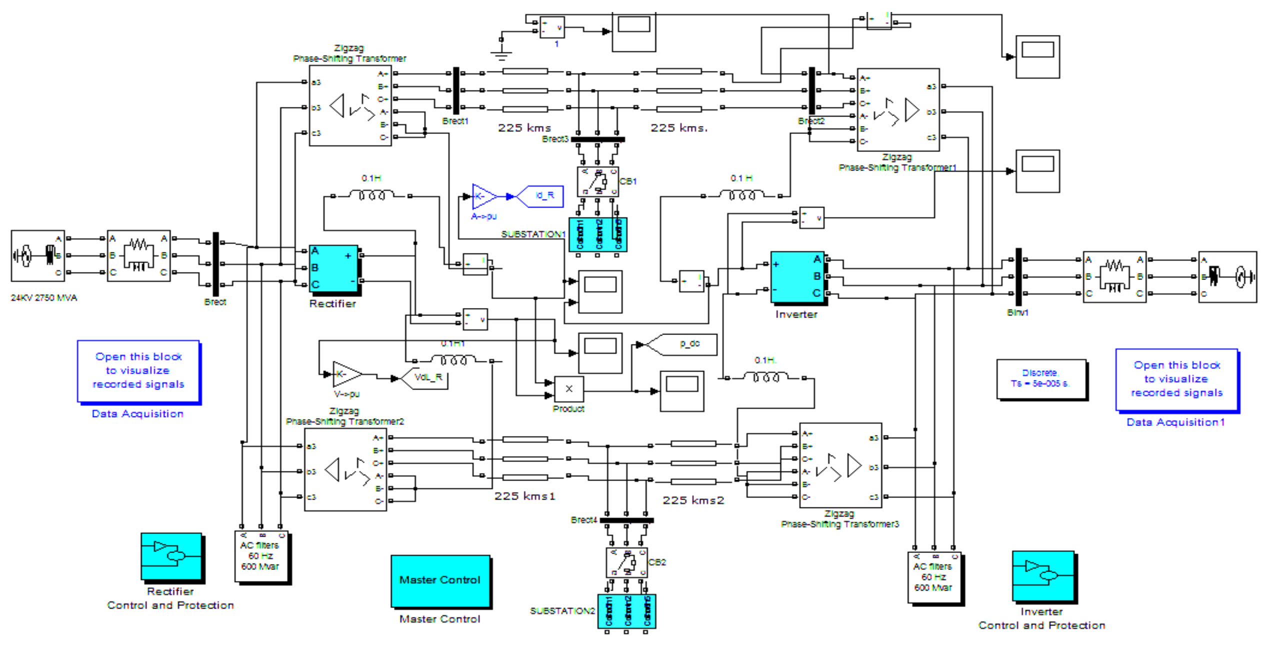
Case A: Equal Power Tapping from Each Line of the Double-Circuit Line at Different Instants

The system is initially considered to be delivering the scheduled real power to an infinite bus. At time 0.5 s, a load of 50 MW is switched on by closing the CB of one tapping station transformer which is directly located in the midway (i.e., at 225 km from the sending end). Subsequently, at time 4.5 s, another load of 50 MW is switched on by closing the CB of the second tapping station transformer which is connected directly to the second line.

Case B: Unequal Power Tapping from Each Double-Circuit Line at Different Instants

The system is initially assumed to be operating at same conditions as mentioned in case A,

Figure 7: Simulink Block Diagram for Simultaneous ac-dc Transmission System



delivering the scheduled real power to an infinite bus. At time 0.5 s, a load of 100 MW was switched on by closing the CB of one tapping station transformer which is directly connected to one of the double-circuit lines located midway (i.e., at 225 km from the sending end).

Subsequently, at time, 3.5 s, another load of 50 MW was switched on by closing the CB of the second tapping station transformer connected to the second line.

SIMULATION RESULTS

Simulation results clearly indicate that the tapping of a small amount of ac power from the composite ac-dc transmission line has a negligible impact on the normal functioning of the composite ac-dc power transmission system.

Figure 8: Transformer Primary Line Currents

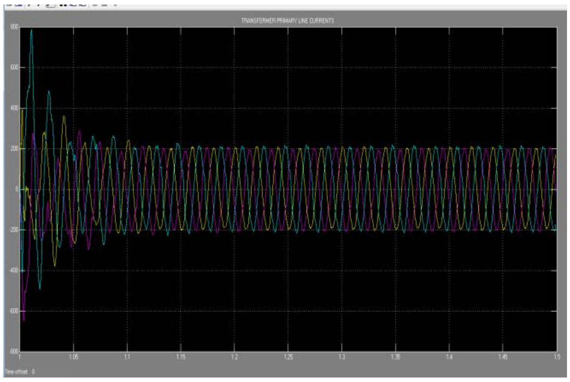


Figure 9: Tap Substation Phase Voltage on the Local Load Side

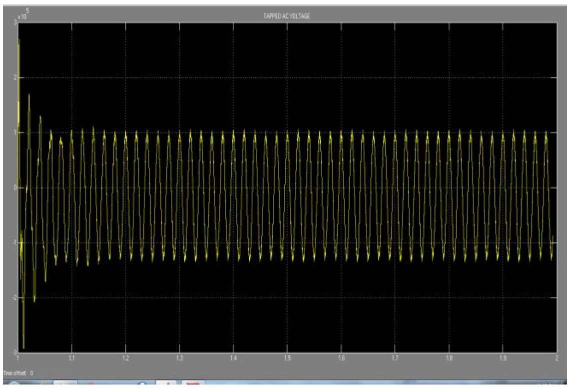


Figure 10: Tap Power (P_{t1}), Receiving End (P_{ac}) ac Power, Sending End (P_{acs}) ac Power, and Receiving End dc Power (P_{invdc})

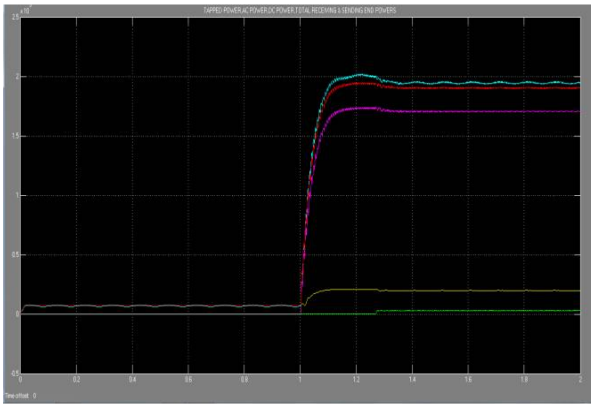
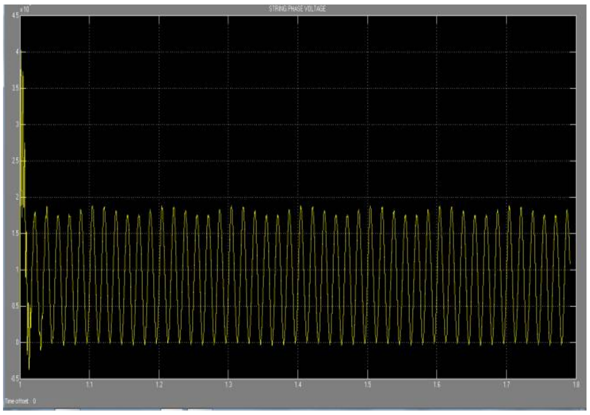


Figure 11: String Phase Voltage



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 feasibility of tapping a small amount of power to feed remotely located communities in the same simple way as tapping in the case of an EHV ac line is demonstrated for the composite ac-dc transmission system. It is also economical compared to complicated methods of tapping from the HVDC line. The results clearly demonstrate that the tapping of a small amount of ac component of power from the composite ac-dc transmission line has a negligible impact on the dc power transfer.

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