

Power Transmission of AC-DC Supply in a Single Composite Conductor

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Abstract

A recently proposed concept of simultaneous ac–dc power transmission enables the long extra high-voltage ac lines to be loaded close to their thermal limits. The conductors are allowed to carry a certain amount of dc current superimposed on usual ac. This paper gives 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 power angle, stability and damping out oscillations and reduce transmission line losses and also we can tap the power in rural areas in very least economical basis. The proposed scheme is digitally simulated with the help of a MATLAB/SIMULINK 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: MATLAB/SIMULINK Simulation, Simultaneous AC–DC Power Transmission, Simultaneous AC–DC Power Transmission

I. INTRODUCTION

In Presently, 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. Techno-economic 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.

In the past, a number of schemes have been proposed for small power tapping from HVDC lines. Most of these schemes use forced commutated or line commutated inverters to tap off the power from the HVDC system. These schemes inherently required additional commutation circuitry or local generation which, in turn, leads to the high cost of installations and operational complications.

Ekstrom and Lamell have proposed a scheme for small power tapping from an HVDC line based on a current source line-commutated single-phase thyristor bridge, connected in series with the HVDC line. To start the tap operation, a local dc voltage source is required in this scheme.

The available bulk electric energy can also be wheeled by simultaneous ac-dc power transmission recently proposed by the authors. In this scheme, the conductors are allowed to carry superimposed dc current along with ac current. The feasibility of simultaneous ac-dc power transmission has been proved by laboratory modeled experimental verification as well as digital simulation. Substantial power upgrading has already been demonstrated by converting the EHV ac line into a composite ac-dc transmission line without any alteration. The transmission angle can be increased up to 80° in a composite ac-dc line without losing transient stability, which is impossible in a pure EHV ac line.

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 transmission of AC-DC supply in single composite conductor. 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.

II. SIMULTANEOUS AC-DC TRANSMISSION LINE:

The main requirements of simultaneous ac-dc transmission line are 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 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.
- A synchronous machine is feeding power to infinite bus via a double circuit, three-phase, 400-KV, 50-Hz, 450-Km AC transmission line. 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.
- Short interruption of the power supplies should be tolerable at the occurrence of temporary earth faults on the main simultaneous ac-dc power transmission system. Further, any fault occurring within tapping station and its local AC network is to be cleared by local CBs.

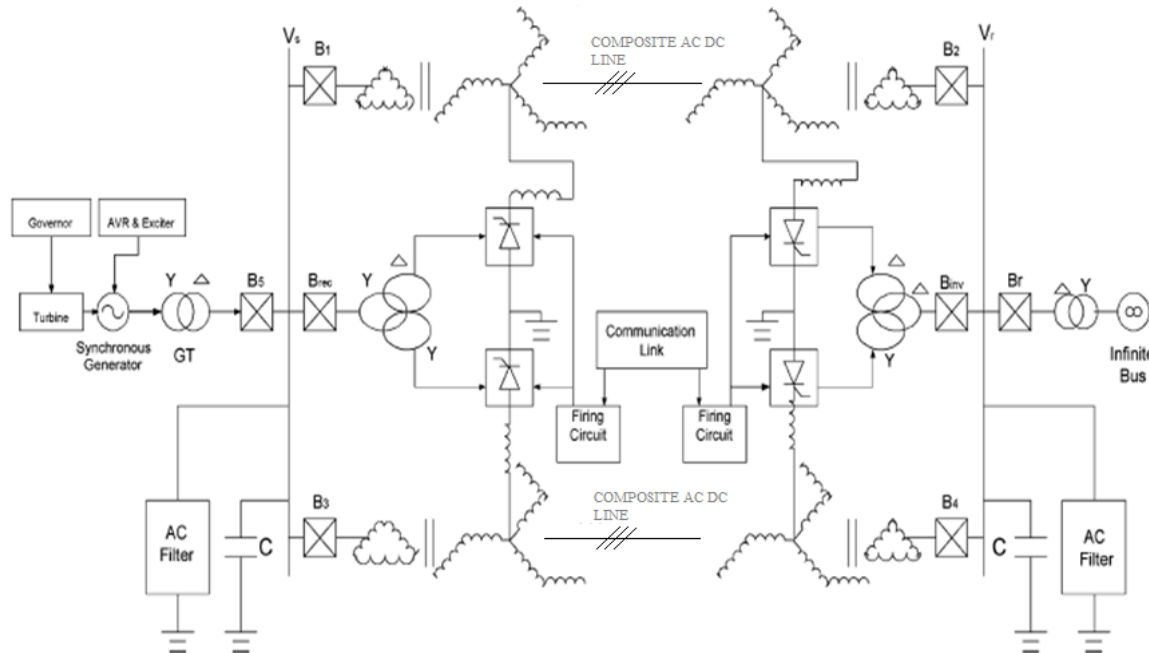


Fig. 1(a): Single-line diagram of basic composite ac-dc transmission system

III. SYSTEM UNDER STUDY

The network depicted in Fig. 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 modeling details of the network components are described. A synchronous machine is delivering power to an infinite bus via a double-circuit three-phase, 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 $1/\sqrt{2}$ 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. 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. A high value of 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. 1(b). 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 parameters per phase of each line. R_{cr} , R_{ci} are commutating resistances, and, α , γ are firing and extinction angles of rectifier and inverter, respectively. Neglecting the resistive drops in the line conductors and transformer windings due to dc current, expressions for ac voltage and current, and for active and reactive powers in terms of A, B, C, and D parameters of each line may be written as

$$E_S = A \cdot E_R + B \cdot I_R \quad (1)$$

$$I_S = C \cdot E_R + D \cdot I_R \quad (2)$$

$$P_S + jQ_S = -E_S \cdot E_R / B^* + D \cdot E^2 / B^* \quad (3)$$

$$P_R + jQ_R = E_S \cdot E_R / B^* - A \cdot E^2 / B^* \quad (4)$$

Fig. 2(a) shows the line-to-ground voltage (i.e., phase voltage) characteristic of the composite ac-dc line which is offset from zero as it possesses a dc voltage component superimposed on a sinusoidally varying ac voltage component. Since the line-to-line voltage does not carry any dc component, it has a pure ac waveshape as demonstrated in Fig. 2(b). The composite-line conductor current characteristic illustrated in Fig. 2(c) indicates the presence of a dc component injected along with an ac component whereas Fig. 2(d) shows the current characteristic at the input of the tap substation. The voltage and current waveforms at the tap substations as depicted in Fig. 2(b), (d), and (e), indicate neither the presence of the dc component nor distortion in waveforms though these are derived from the composite line. To tap ac power from the line, the transformer can be directly connected to the conductors of the line without breaking them.

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 Fig. 1(b). These CBs are provided for local protection, to clear the fault within the local ac network. The nature of the local load considered here is that of a summertime residential class with the following characteristics:

- power factor=0.9;
- voltage index for power ($9P/9V$)=1.2;
- voltage index for Q ($9Q/9V$)=2.9;
- frequency index for power ($9P/9f$)=0.8;
- frequency index for Q ($9Q/9f$)= -2.2.

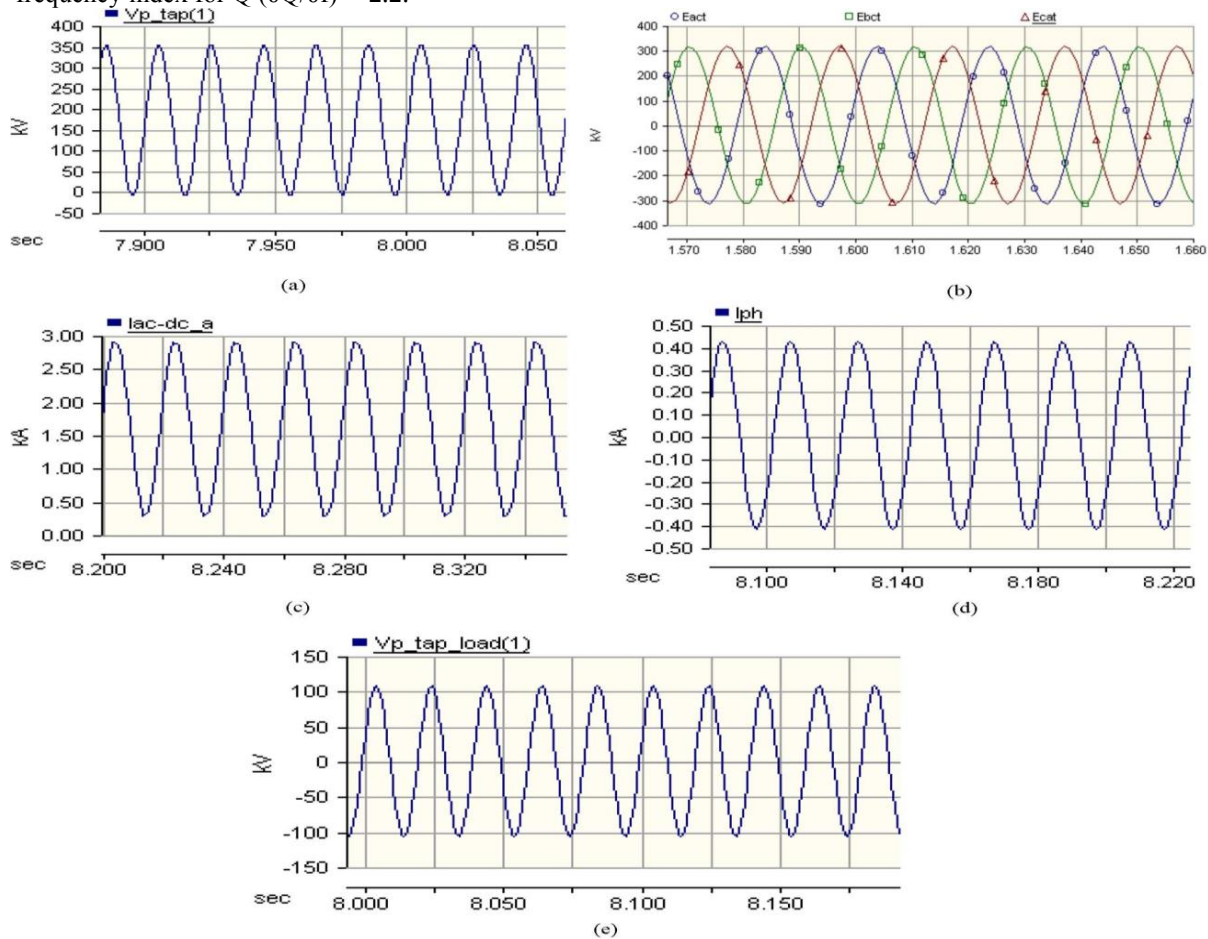


Fig. 2. (a) Line-to-ground (phase) voltage of the composite ac-dc line. (b) Three-phase line-to-line voltages in the composite ac-dc line at the tapping point of the substation input. (c) Phase A conductor current in the composite ac-dc line. (d) Phase A current at the input of the tap substation at a particular load. (e) Tap substation phase voltage on the local load side.

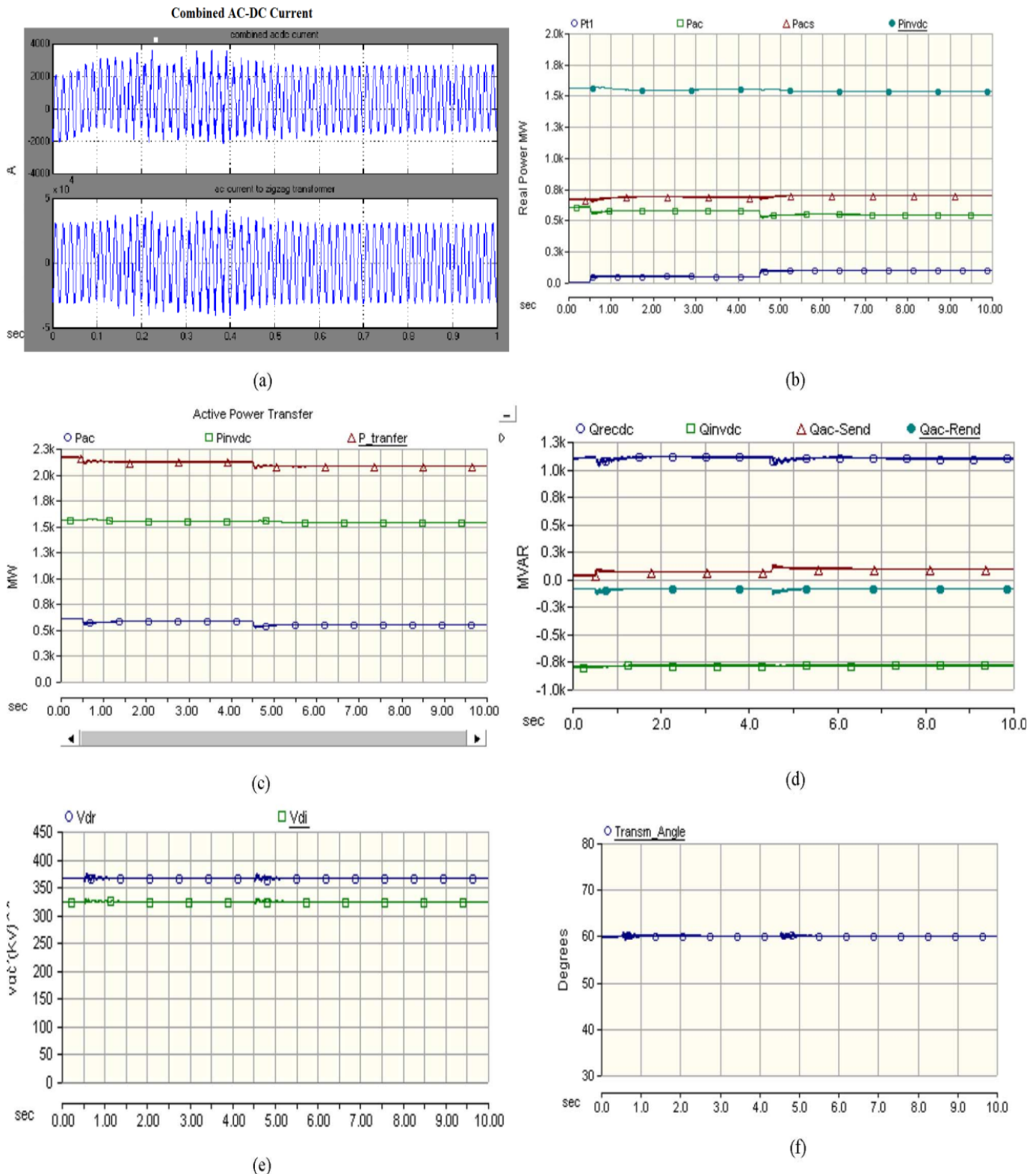


Fig. 3: (a) Combined AC-DC Current. (b) Tap power (Pt1), receiving end (Pac) ac power, sending end (Pacs) ac power, and receiving end dc power (Pinvdc). (c) AC (Pac), dc (Pinvdc), and total (P_transfer) power transfer at the receiving end. (d) Qreacdc and Qinvc reactive power drawn by the rectifier and inverter. Qac-send and Qac-Rend reactive power drawn by the lines from each end. (e) Rectifier (Vdr) and inverter (Vdi) dc voltages. (f) Transmission angle (Transm_Angle).

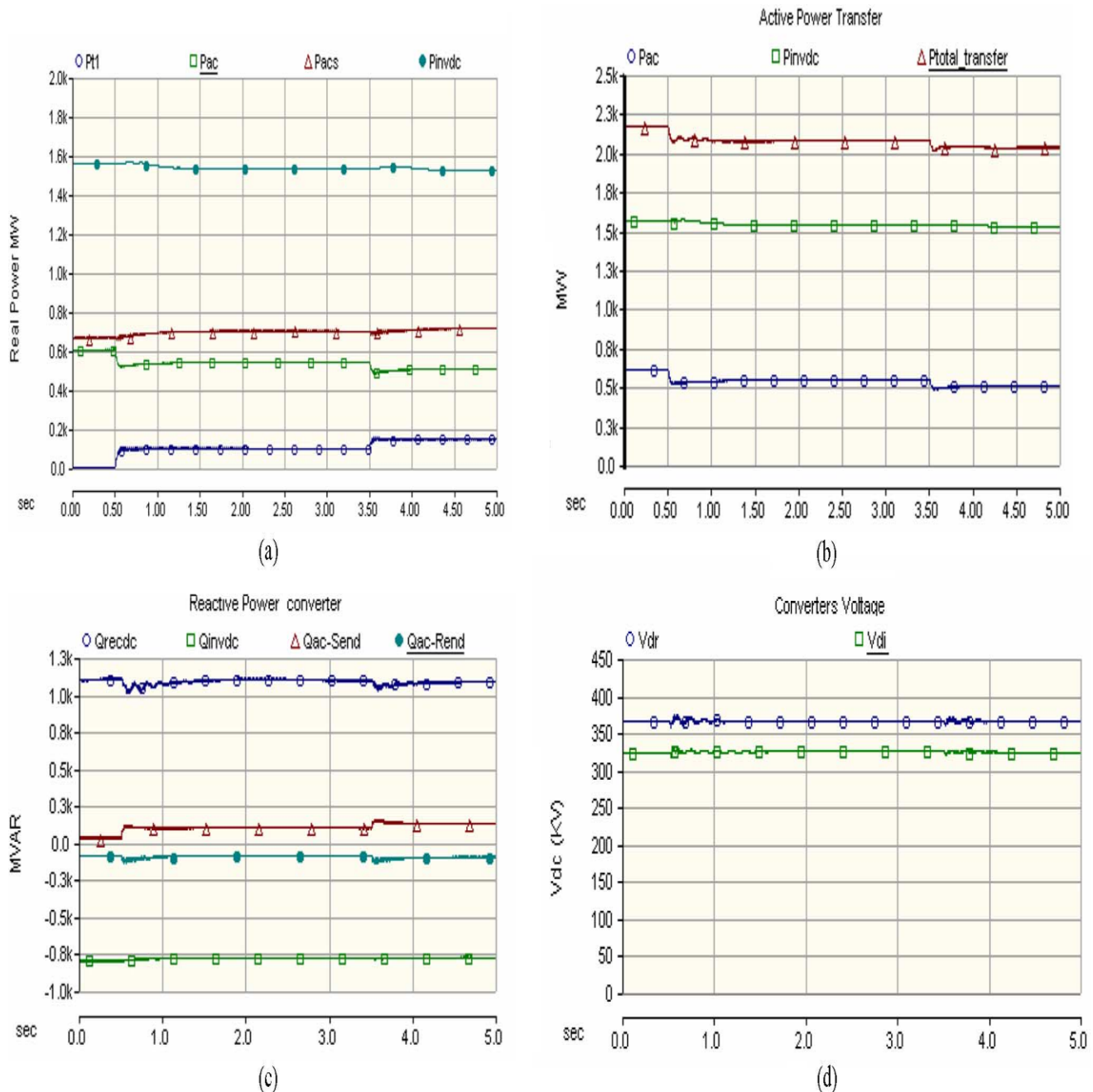


Fig. 4(a): Tap power (P_{t1}), receiving end (P_{ac}) ac powers, sending end (P_{acs}) ac power, and receiving end dc power (P_{invc}). (b) AC (P_{ac}), dc (P_{invc}), and total ($P_{transfer}$) power transfer at the receiving end. (c) Q_{reacdc} , Q_{invc} reactive power drawn by the rectifier and inverter. $Q_{ac-Send}$ and $Q_{ac-Rend}$ reactive power drawn by the line from each end. (d) Rectifier (V_{dr}) and inverter (V_{di}) dc voltages.

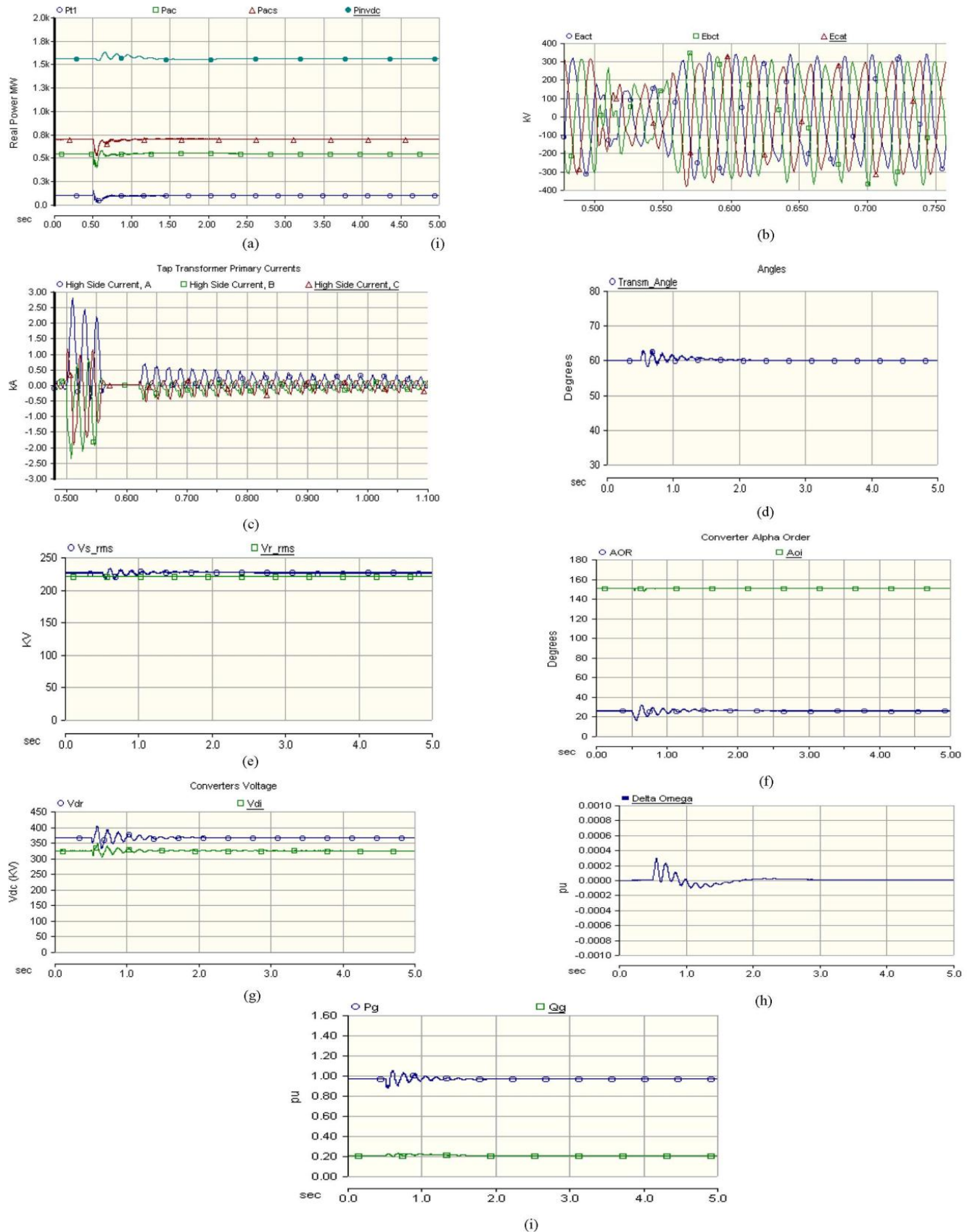
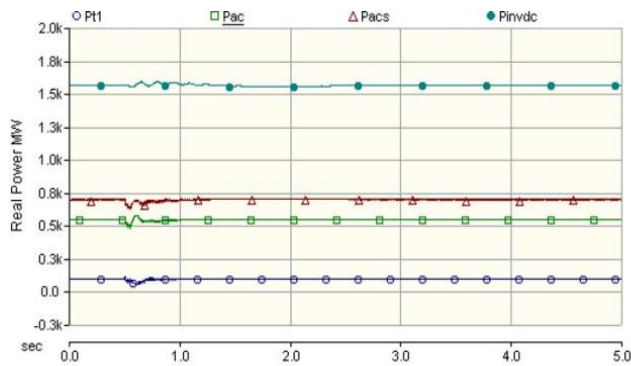
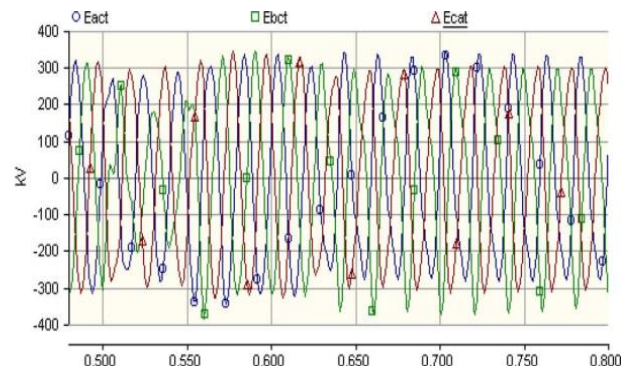


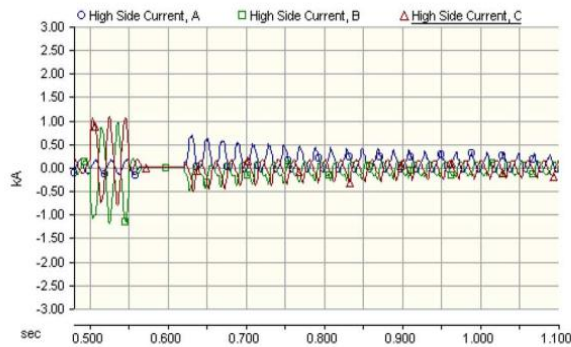
Fig. 5: (a) Tap power (Pt1), receiving end (Pac) ac power, sending end (Pacs) ac power, and receiving end dc power (Pinvc). (b) Line voltage variations across the CB's input. (c) Transformer input line currents variations measured at the CB's input. (d) Transmission angle (Transm_Angle). (e) Sending (Vs_rms) and receiving (Vr_rms) end bus voltages. (f) Rectifier (AOR) and inverter (Aoi) firing angle order. (g) Rectifier (Vdr) and inverter (Vdi) dc voltages. (h) Generator's speed deviation (delta omega). (i) Generator's active (Pg) and reactive (Qg) power output.



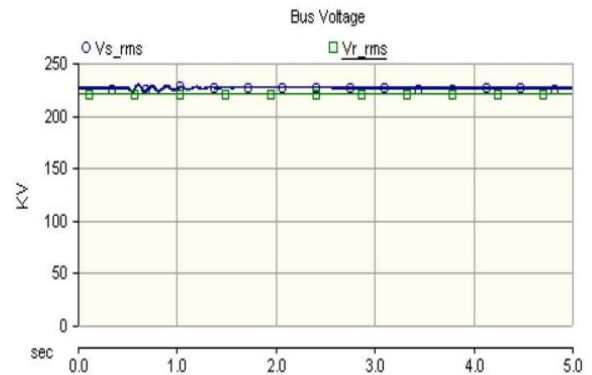
(a)



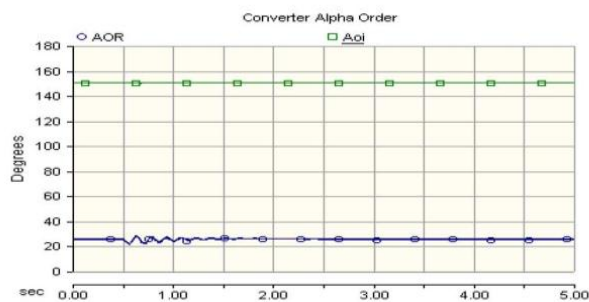
(b)



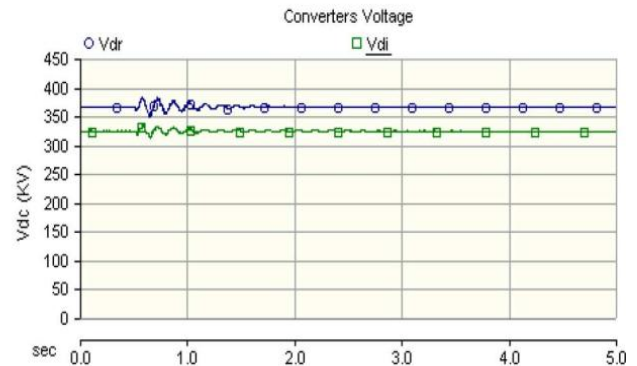
(c)



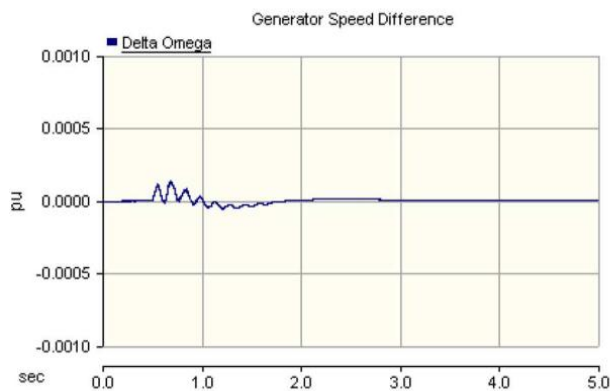
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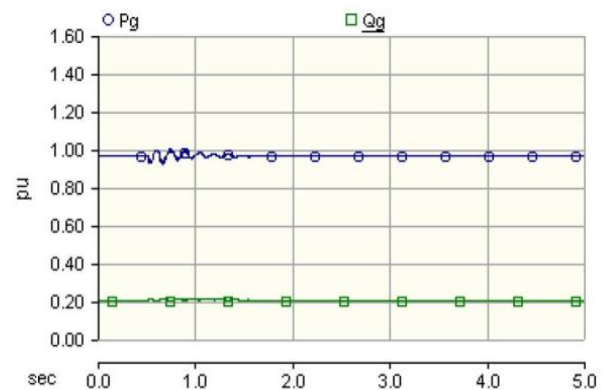
(e)



(f)



(g)



(h)

Fig. 6(a): Tap power (Pt1), receiving end (Pac) ac power, sending end (Pacs) ac power, and receiving end dc power (PinvdC). (b) Line voltage variations across the CB's input. (c) Transformer input line currents variations measured at the CB's input. (d) Sending (V_{s_rms}) and receiving-end (V_{r_rms}) bus voltages. (e) Rectifier (AOR) and inverter (Aoi) firing-angle order. (f) Rectifier (V_{dr}) and inverter (V_{di}) dc voltages. (g) Generator's speed deviation (delta omega). (h) Generator's active (P_g) and reactive (Q_g) power output.

IV. DIGITAL SIMULATION OF THE PROPOSED SCHEME

In order to examine the feasibility of the proposed scheme for power transmission of AC-DC supply in single conductor and to observe the performance of the composite ac-dc power transmission system under various operating conditions, the digital simulation software packages both in MATLAB and PSCAD/EMTDC was used.

V. CONCLUSION

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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