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Asynchronous Power Flow Controller

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ABSTRACT-In the present system demand of electrical power increases so fast and transfer of electrical power is need of today's scenario. . The electrical power is transfer at same frequency through AC transmission line. However, power generation may be at different frequencies such as wind generation, sources at islanding or power generation in different countries. The proposed Asynchronous Power Flow Controller (APFC) system essentially consists of two back-to-back voltage source converters as "Shunt Converter" and "Series Converter" which is coupled via a common dc link provided by a dc storage capacitor This paper suggests the power transfer and control between the sources operating at different or same frequencies.
***Keywords* -** Shunt converter, Series Converter, Phasor, Direct-drive, National grids.

I. INTRODUCTION

Electric power system is widely interconnected. These interconnections enable taking advantage of diversity of load centers in order to minimize the total power generation capacity and fuel cost. Transmission interconnections enable taking advantage of diversity of loads, availability of sources, and fuel price in order to supply electricity to the loads at minimum cost with a required reliability [1] Presently, for the large power system interconnections the AC link and DC link are two options available. Since, AC is the dominant mode of generation, transmission and distribution in power system; therefore, interconnections have been mostly realized by AC link since this option is technically feasible and economically justified [2]. The proposed APFC system is a combination of back-to-back voltage source converters labeled as "Shunt Converter" and "Series Converter" in the Fig. 1, which are coupled via a common dc link provided by a dc storage capacitor. Thus, the APFC system placed in ac tie line between two separate power systems or grids. Interconnection of two separate power systems or grids operating at different frequencies is possible if frequency of current as well as voltage both must be maintained.

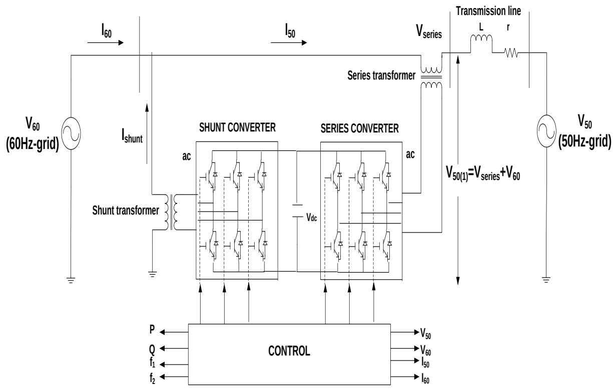


Fig. 1. Implementation of the APFC by two back-to-back voltage source converters.

II. APFC SYSTEM

The APFC system consists of series converter and shunt converter. The basic series converter with two separate power systems or grids as shown in Fig. 2(a).It is observed that

$$\mathbf{V_{50(1)}} = \mathbf{V_{series}} + \mathbf{V_{60}} \tag{1}$$

Where,

$$\mathbf{V_{60}} = \mathrm{V_{m60}} \sin(2\pi f_1 t) \tag{2}$$

$$f_1 = 60 \text{ Hz}$$

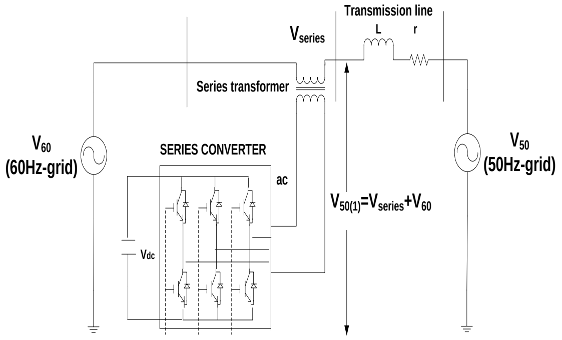
$$\mathbf{V_{50(1)}} = \mathrm{V_{m50}} \sin(2\pi f_2 t) \tag{3}$$

$$f_2 = 50 \text{ Hz}$$

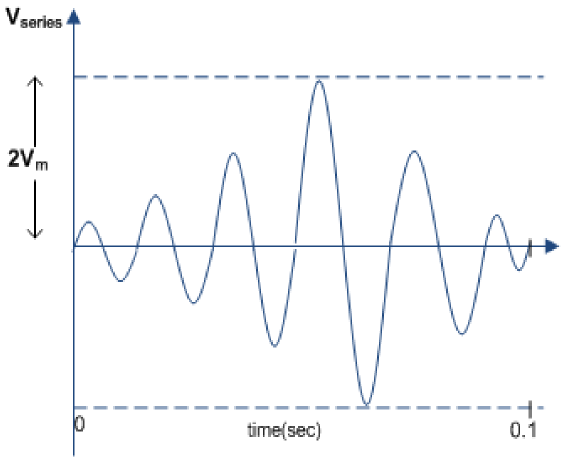
Where,

$V_{m60} = V_{m50} = V_m$

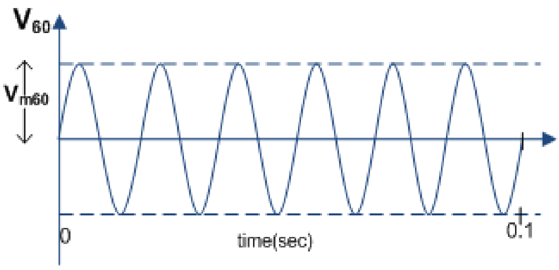
$\mathbf{V_{50(1)}}$ is the resultant vector of $\mathbf{V_{series}}$ and $\mathbf{V_{60}}$ vectors. The function of series converter is to injecting a voltage $\mathbf{V_{series}}$ with magnitude V_{series} and phase angle θ through a series-connected transformer. This injected voltage as shown in Fig. 2(b) is a difference of two separate power systems or grids voltage having different frequencies, shown in Figures. 2 (c) and 2(d).



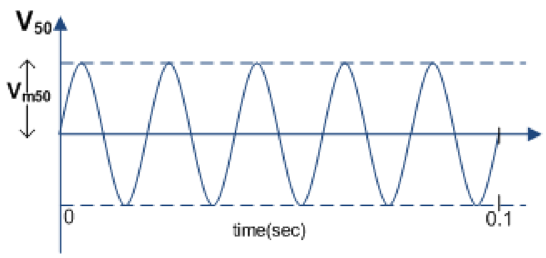
(a)



(b)



(c)



(d)

Fig. 2: (a).Basic circuit arrangement of series converter with two separate power systems or grids (b) Series converter injected voltage waveform (c) 60 Hz-grid voltage waveform.(d) 50 Hz-grid voltage waveform.

The basic shunt converter with two separate power systems or grids as shown in Fig. 3(a).It is observed that

$$\mathbf{I_{50}} = \mathbf{I_{shunt}} \qquad (4)$$

Where,

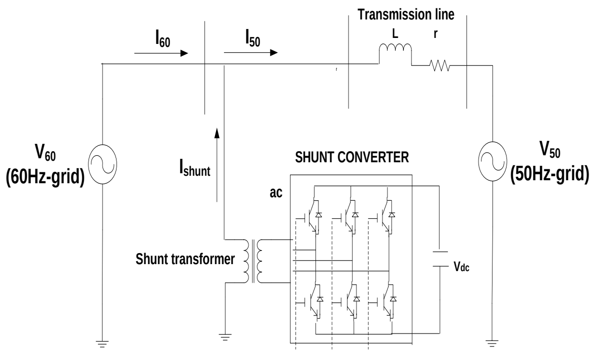
$$\mathbf{I_{60}} = I_m \sin(2\pi f_1 t) \qquad (5)$$

$$\mathbf{I_{50}} = I_m \sin(2\pi f_2 t) \qquad (6)$$

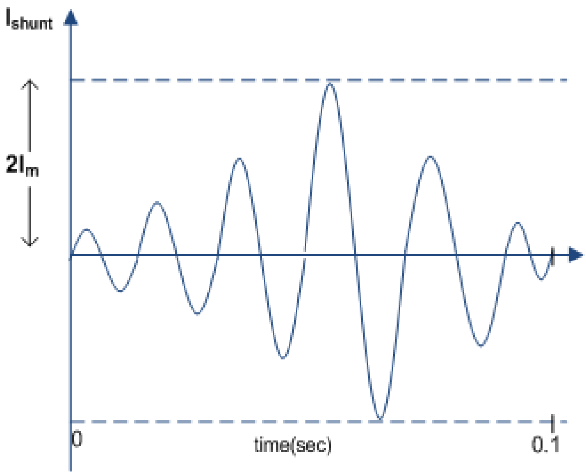
Where,

$I_{m60} = I_{m50} = I_m$

The basic function of shunt converter is to injecting a current $\mathbf{I_{shunt}}$ in shunt with line via a shunt-connected transformer. This injected current as shown in Fig. 3(b) is a difference of two separate power systems or grids current having different frequencies, shown in Figures. 3(c) and 3(d).



(a)



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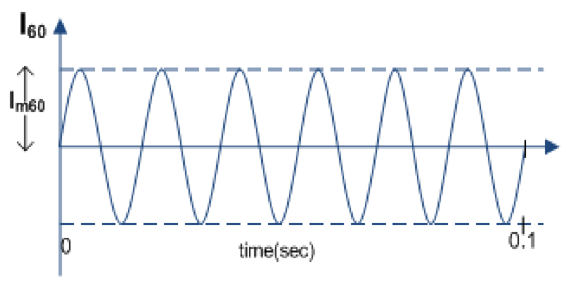
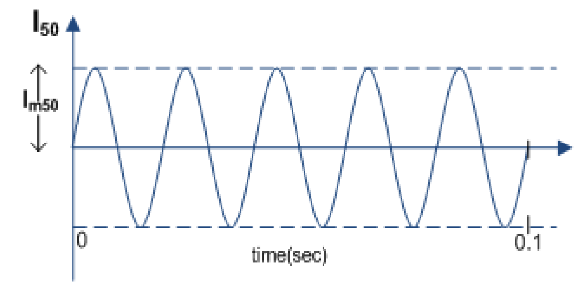


(c)



(d)

Fig. 3: (a) Basic circuit arrangement of shunt converter with two separate power systems or grids (b) Shunt converter injected current waveform (c) 60 Hz-grid current waveform (d) 50 Hz-grid current waveform.

A simplified block diagram of two back-to-back voltage source converters labelled as "Shunt Converter" and "Series Converter" in the Fig. 4, which are coupled via a common dc link provided by a dc storage capacitor. The APFC system allows bidirectional flow of real power between the converters as well as frequency maintenances of two sources operating at different frequencies.

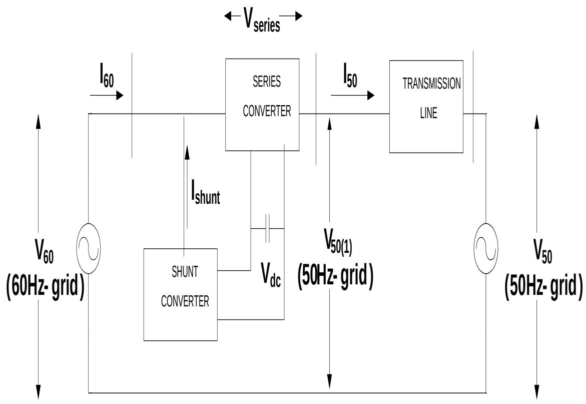


Fig. 4. Proposed APFC block diagram.

2.1, MATHEMATICAL ANALYSIS

Suppose the two alternators having frequencies of f_1 and f_2 respectively [3], as shown in Fig. 5, let the voltage equations of two alternating source are

$$V_1 = V_m \sin\omega_1 t \quad (7)$$

$$V_2 = V_m \sin\omega_2 t \quad (8)$$

Then for equal voltage magnitude, the voltage across the switch S_1 as shown in below Fig.6, is

$$v = V_1 - V_2 \quad (9)$$

From equations (7) and (8),

$$v = V_m \sin\omega_1 t - V_m \sin\omega_2 t. \quad (10)$$

With the help of trigonometric relation

$$\sin x - \sin y = 2.\cos\frac{x+y}{2}.\sin\frac{x-y}{2}$$

Hence, the above equation can be written as

$$v = 2V_m [\cos\{\frac{f_1+f_2}{2}(2\pi t)\}.\sin\{\frac{f_1-f_2}{2}(2\,\pi t)\}] \quad (11)$$

The curve nature of equation (4) as shown in Fig. 6 shows amplitude of voltage changes from zero to twice the maximum amplitude and again to zero continuously. The injected voltage by series converter will follow the equation (11)

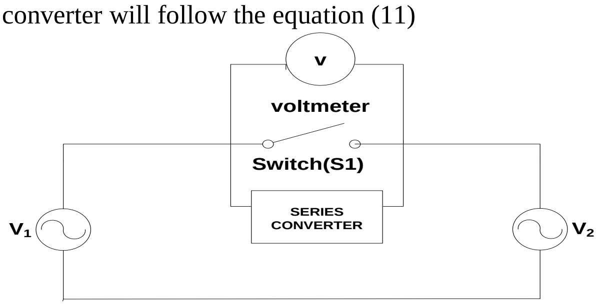


Fig. 5. Basic circuit diagram of two alternating source with switch connected in series.

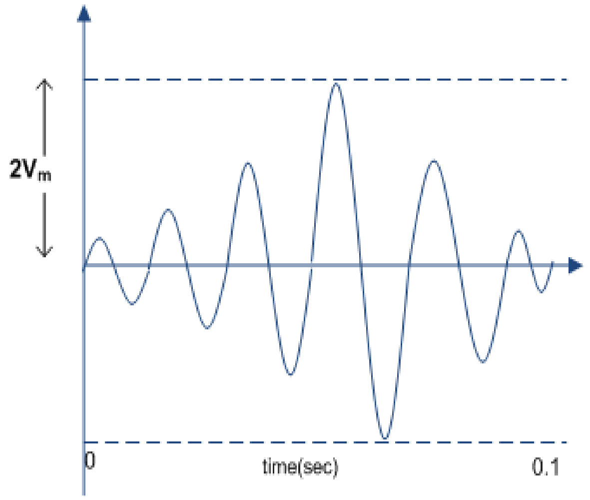
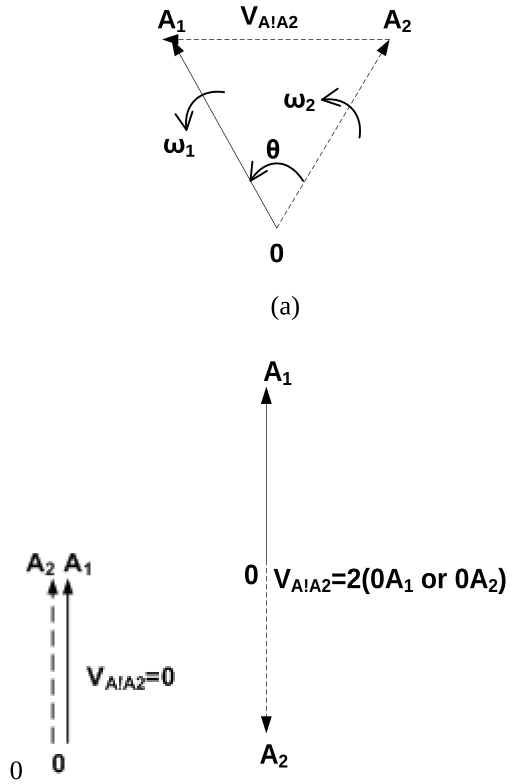


Fig. 6. Voltage across the switch which is to be injected by series converter.

In Fig. 7(a), phase voltages of two alternating source are represented by phasors $\mathbf{OA_1}$ and $\mathbf{OA_2}$ rotating at angular speed of ω_1 and ω_2 rad/sec respectively. When rotating tips A_1 and A_2 coincide, voltage across the switch will be zero as shown in Fig. 7(b). When rotating tips A_1 and A_2 opposite to each other voltage across the switch will be twice the magnitude of single phasors (OA_1 or OA_2) as shown in Fig.7 (c).



(b) (c)

Fig. 7. Phasor diagram pertaining to the synchronization of an alternator with another alternator or bus-bar (a) Phasors **OA_1** and **OA_2** having angle 'θ' in between them. (b) Phasors **OA_1** and **OA_2** coincides. (c) Phasors **OA_1** and **OA_2** opposite to each other.

III. SIMULATION MODEL

Parameters for simulation are as given in table 1:

Table 1: Simulation Parameters

Sr. No.	Parameters	Values
1	60 Hz-grid Voltage (line voltage)	33 kV
2	50 Hz-grid Voltage (line voltage)	33 kV
3	Transmission line inductance(per phase)	0.111464 H
4	Transmission line resistance(per phase)	5 Ω
5	Load angle(60 Hz-grid)	0°
6	Load angle(50 Hz-grid)	30° lagging
7	dc link capacitor	1 µF

Three AC voltage sources are used as phase V_{r60}, phase V_{y60} and phase V_{b60} for 60 Hz-grid and other three AC voltage sources are used as phase V_{r50}, phase V_{y50} and phase V_{b50} for 50 Hz-grid. Fig.8 shows the simulation model of The APFC system is used for interconnection of 60 Hz grid and 50 Hz grid.

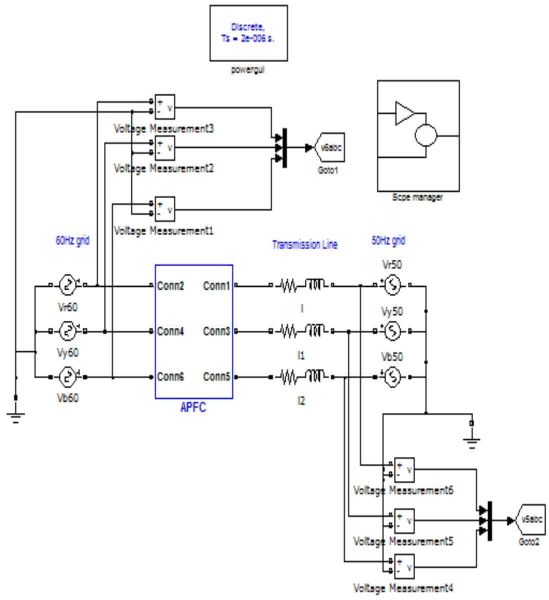


Fig. 8. Simulink model of proposed APFC system.

IV. SIMULATION RESULTS

As shown in Fig. 9 series converter injected voltage amplitude continuously changes from zero to twice of maximum value of phase voltage and again to zero repeatedly, which maintain 60 Hz-grid voltage shown in Fig. 10 and 50 Hz-grid voltage shown in Fig. 11.

This series injected voltage, is a difference of 60 Hz-grid and 50 Hz-grid voltage, modulated with high frequency triangular wave decide the triggering of IGBT's used for series converters.

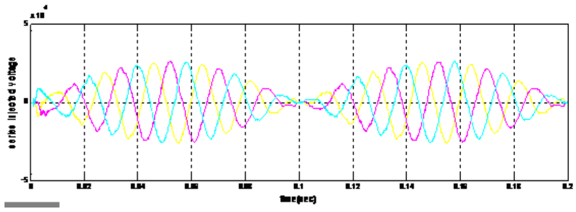


Fig. 9. Series converter injected voltage waveform. Scale: 50 kV/div, 2 ms/div

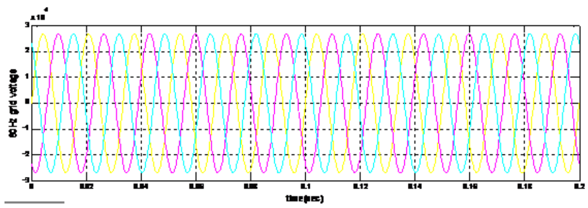


Fig. 10. 60 Hz grid voltage waveform. Scale: 10 kV/div,2 ms/div

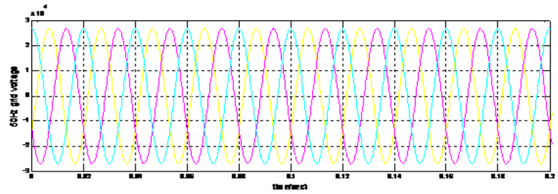


Fig. 11. 50 Hz grid voltage waveform. Scale: 10 kV/div,2 ms/div

Shunt converter uses hysteresis current control scheme decide the triggering of IGBT's used for shunt converters. As shown in Fig. 12 shunt converter injected current amplitude continuously changes from zero to twice of maximum value of phase current and again to zero repeatedly, which maintain 60 Hz-grid current shown in Fig. 13. and 50 Hz-grid current shown in Fig. 14. As amplitude of injected current reaches zero distortion in current magnitude and phase angle changes takes place.

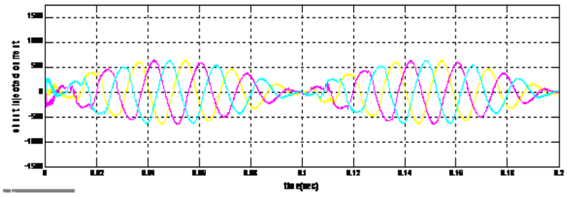


Fig. 12. Shunt converter injected current waveform. Scale: 500 A/div, 2 ms/div

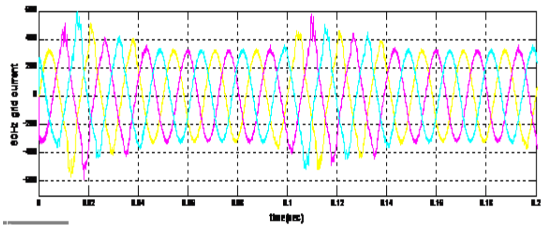


Fig. 13. 60Hz grid current waveform. Scale: 200 A/div,2 ms/div

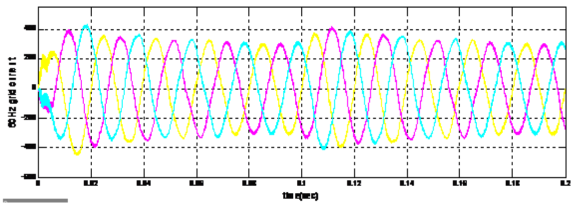


Fig. 14. 50 Hz grid current waveform. Scale: 200 A/div,2 ms/div

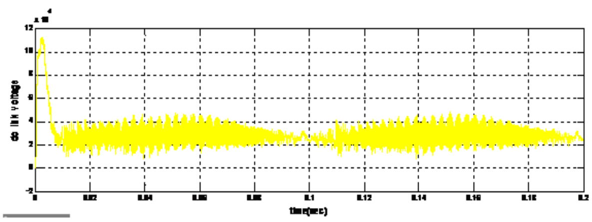


Fig. 15. dc link voltage. Scale: 20 kV/div, 2 ms/div

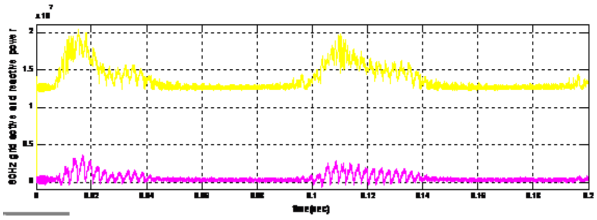


Fig. 16. 60 Hz grid active and reactive power. Scale: $5*10^6$/div, 2 ms/div

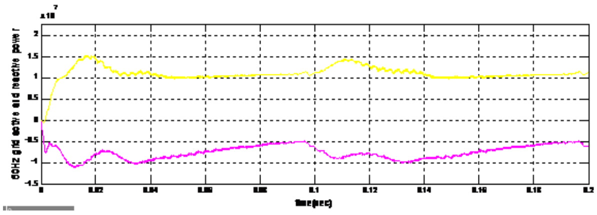


Fig. 17. 50 Hz grid active and reactive power. Scale: $5*10^6$/div, 2 ms/div

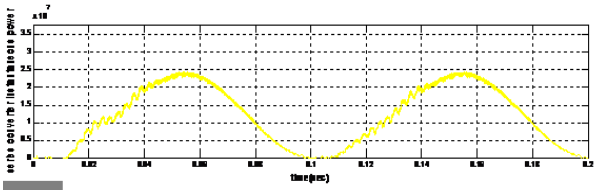


Fig. 18. Series converter instantaneous real power. Scale:5 MW/div, 2 ms/div

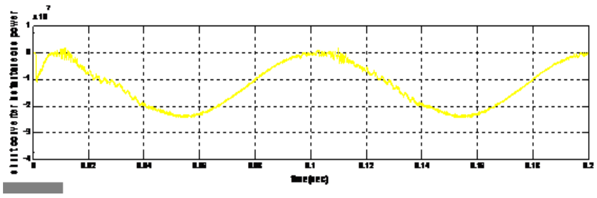


Fig. 19. Shunt converter instantaneous real power. Scale: 5 MW/div, 2 ms/div

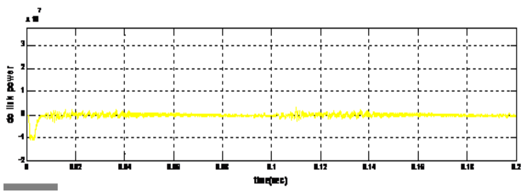


Fig. 20. dc link average power. Scale: 10 MW/div, 2 ms/div

Fig. 15 shows dc link voltage to be 30 kV, and active power transfer from 60 Hz grid (13 MW) shown in Fig. 16, to 50 Hz grid (10 MW) shown in Fig. 17.

Fig. 18 shows series converter absorbing instantaneous real power, Fig. 19 shows shunt converter injecting instantaneous real power and Fig. 20 shows average power in dc link is zero.

V. CONCLUSION

This paper suggests a new Asynchronous Power Flow Controller (APFC) for interfacing two independent power systems or grids operating at different or same frequencies. Since, ac is the dominant mode of generation, transmission and distribution in power system. Thus, the APFC system placed in ac tie line between two separate power systems or grids. The proposed APFC system can also be used in joining Direct- drive wind turbine with grid or joining national grids frequency is a continuously changing variable in real time.

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