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An Advanced Full-Bridge Three Level DC-DC Converter with Voltage Balancing Control Technique for Wind Power Systems

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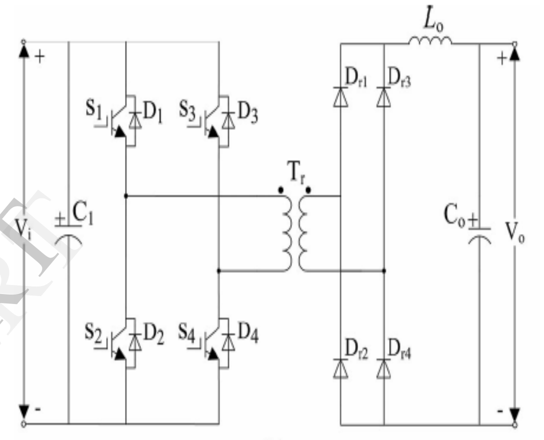
Abstract— This paper presents an advanced full-bridge three level DC-DC converter and its control for wind power systems. A passive filter is used to improve the performance of the proposed converter. The presence of passive filter reduces the voltage stress of the medium frequency transformer in the AFBTL DC-DC converter. A modulation strategy is proposed for the AFBTC DC-DC converter, which provides two operating modes. Furthermore, a voltage balancing control of the wind turbine based on the AFBTL DC-DC converter in a DC-grid system is presented. Finally, the simulation results for the proposed AFBTL DC-DC converter with 1KW output power range is presented and obtained merely to the theoretical values.

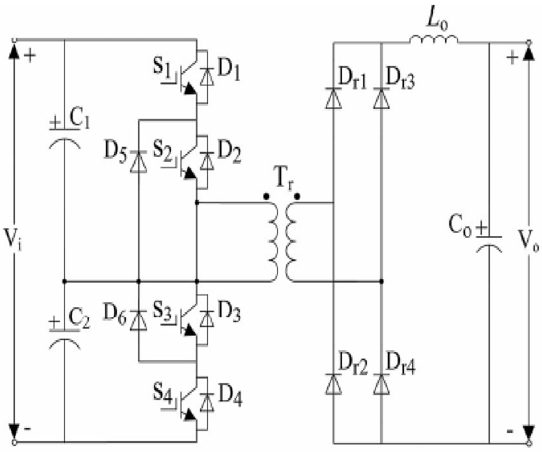
Keywords- Full bridge three level (FBTL) converter, half bridge three level (HBTL) converter, permanent magnet synchronous generator (PMSG), DC-DC converter, wind turbine, voltage balancing control, pulse width modulation (PWM) .

I INTRODUCTION

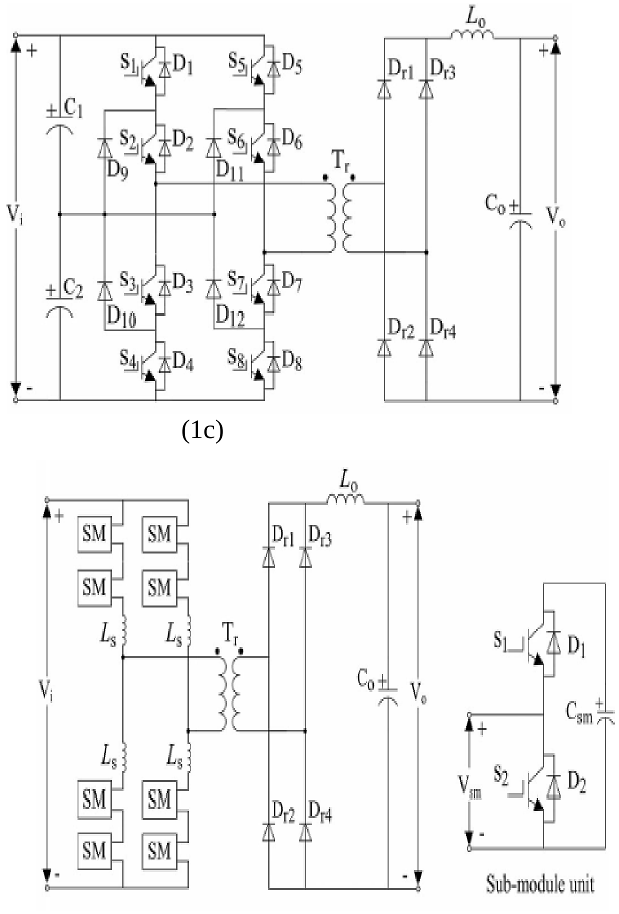
In general, the DC grid provides advantageous things such as absence of reactive power, harmonics and power factor, which gives an effective solution for the power collection system for the growing power demand in the present days. The offshore wind turbines are mostly connected to a DC grid to deliver DC power to a medium or high DC voltage networks. To minimize power delivery and the DC connection, a high efficient DC-DC converter is required. Generally, the voltage level of the DC network is much higher than the input voltage level of the DC-DC converter. For this reason, a medium frequency transformer (MFT) with a range of hundreds of hertz to several kilohertz operating frequency is used for the DC-DC converter. In addition to providing the boosted output voltage, it provides the galvanic isolation between source and grid.



(1a)



(1b)



(1c)

(1d)

Fig.1. (1a) Basic FB two-level converter. (1b) Basic HB three-level converter. (1c) Basic FB three-level converter. (1d) SMs based-FB three-level converter.

There are many converter topologies which are widely used in the wind power systems as shown in Fig.1. The required number of switching devices for FB-two level inverter is very less compared to remaining three converter configurations. The switches used in the two level converter topology have to take the full DC-bus voltage, and then the voltage rate dv/dt becomes so high. Therefore it leads to large electromagnetic interference (EMI). As compared to two-level configurations, three-level configurations will provide benefits in the fields of power quality, electrical and thermal stress of semiconductors and number of switches required. The switches used in the three level converters will take only half of the DC-bus voltage, it provides less dv/dt ratio compared to FB two-level converter.

The basic FBTL converter has many advantages like reduced voltage stress of the switches, reduced filter size, improved dynamic response and it will be used for medium and high power conversions. Compared to HBTL, FBTL converter and sub modules based (SMs) FBTL converter topologies can provide five-level output voltage to minimize the voltage steps and to reduce the dv/dt ratio.

For the p-level configuration, SMs-based FB converter requires 8(P-1) number of switches, which is more than 2(P-1) and 4(P-1) switches required in the basic HB and FB converters respectively. If we compare the FBTL with SMs based FBTL converter, FBTL converter requires less number of switches and easy to construct. With this reason, FBTL converter is preferred for wind power systems. In this paper, the isolated FBTL DC-DC converter is studied for high-power wind turbine systems as shown in Fig.2.

II PROPOSED CONVERTER

Fig.3 shows the structure of the IFBTL DC-DC converter having eight switches (S_1-S_8), eight freewheeling diodes (D_1-D_8), four clamping diodes (D_9-D_{12}), a medium frequency transformer, four rectifier diodes (D_{r1}-D_{r4}), a passive filter with L_s and $C_{s,}$ an output filter inductor L_d, one output capacitor C_0 and two input voltage divided capacitors C_{i1} and C_{i2}. C_{i1} and C_{i2} are used to split the input DC bus voltage V_i into two equal voltages V_{c1} and V_{c2}.

Apart from the FBTL DC-DC converter, a passive filter is inserted into the IFBTL DC-DC converter to improve the performance of the DC-DC converter as shown in Fig.3. This arrangement provides solution to overcome the problem that the nonlinear characteristics of semiconductor devices with distorted waveforms, harmonics and reduces the voltage stress of the MFT, which is important for the power conversion by converter in the high power applications.

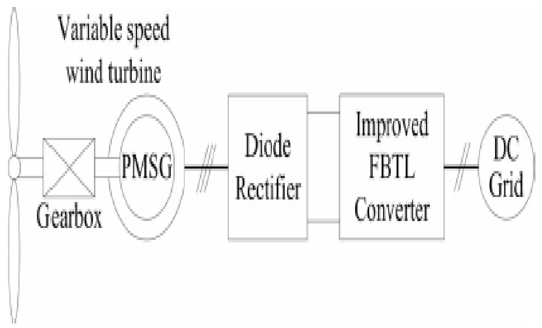


Fig.2. Block diagram of the wind turbine connected to a dc grid.

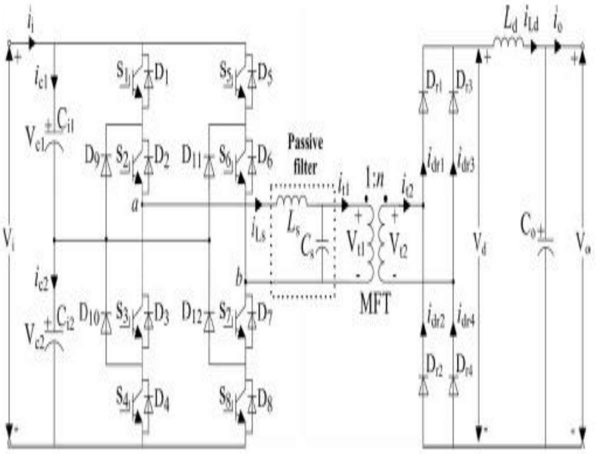
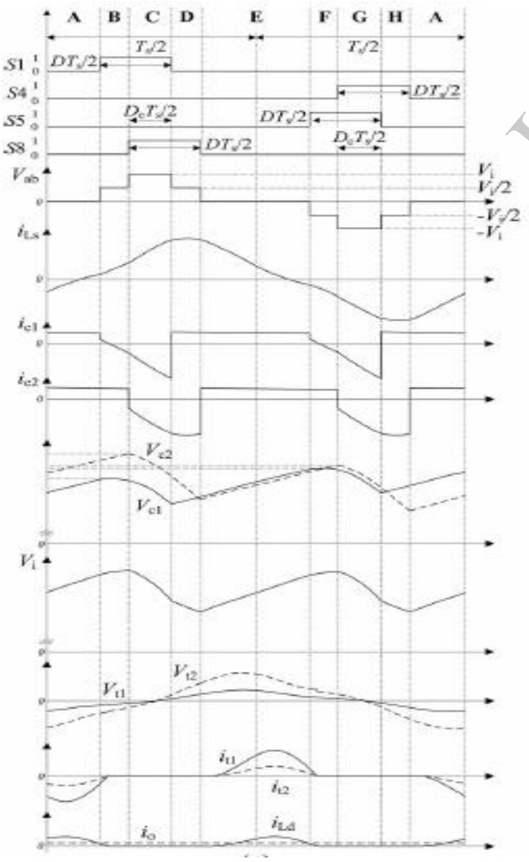


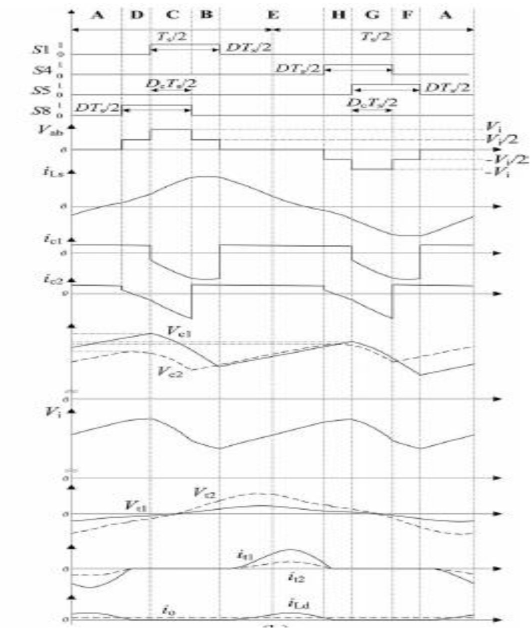
Fig.3. Block diagram of the AFBTL DC-DC converter.

III OPERATION PRINCIPLES

For the successful operation of proposed FBTL DC-DC converter an advanced pulse width modulation technique with two operating modes is proposed and is discussed as below.



(4a)



(4b)

Fig. 4: Key waveforms of the AFBTL DC-DC converter. (4a) in operation mode I. (4b) in operation mode II.

A.PROPSED MODULATION STRATEGY

A PWM technique is used to conduct the switches S_1-S_8 complementally in pairs, i.e., pairs S_1-S_3, S_4-S_2, S_5-S_7 and S_8-S_6 respectively. The duty cycle for S_1 is D. The way of phase shifting the PWM for other switch pair's results in the different operating modes as described below.

1) Operating Mode I:

The PWM waveform for the switch pairs S_8-S_6, S_5-S_7 and S_4-S_2 lags behind the pair S_1-S_3 by $(D-D_c)\ T_s/2$, $T_s/2$ and $(D-D_c+1)/2$ respectively as shown in Fig. 4(a). The term T_s represents the switching cycle. The overlap time between the switch pairs S_1-S_3 and S_8-S_6 is $D_cT_s\ /2$ and is also same for S_4-S_2 and S_5-S_7. The term D_c is nothing but the overlap duty ratio.

2) Operating Mode II:

In this mode of operation, the PWM waveform for the pair S_8-S_6 leads another pair S_1-S_3 by $(D-D_c)T_s/2$ and the waveforms of remaining pairs S_4-S_2 and S_5-S_7 lags the pair S_1-S_3 by $(1-D+D_c)/2$ and $T_s/2$ respectively as shown in Fig 4(b). The overlap time between the group of pairs S_1-S_3, S_8-S_6 and S_4-S_2, S_5-S_7 is same and its value is $D_cT_s/2$.

The main difference between the above mentioned operation modes is change in charge and discharge positions of capacitor in each half cycle as shown in Fig 4.

In mode I, input capacitor C_{i2} in each half cycle as shown in Fig 4b. These two operation modes can be used alternatively for the adaptive voltage balancing control.

B.PROPOSED VOLTAGE BALANCING CONTROL TECHNIQUE

In this chapter, a voltage balancing control technique is proposed for the AFBTL DC-DC converter, which can be analyzed by alternating operating modes I and II.

- *In operation mode I:*

As shown in Fig 4a, capacitor currents i_{c1} and i_{c2} are same with time period of $T_s/2$. The charge and discharge positions for capacitors C_{i1} and C_{i2} in each half cycle is common for states A, C and E. In stage B, current i_{c2} is more than $i_{c1,}$ where i_{c2} is very less than i_{c1} in stage D as shown in Fig 4a. The periods of stages B and D are $(D\text{-}D_s)$ $T_s/2$. For example if $V_{c1}=V_{c2}=V_i/2$; C_{i2} will provide more energy to the load than C_{i1} in the first half cycle during the mode I operation. The situation in the second half cycle is similar to the first half cycle. Consequently, voltage V_{c1} is higher than V_{c2} as shown in Fig 4a, which result in the situation that V_{c1} is greater than V_{c2} in mode I operation.

- *In operation mode II:*

Operation is same compared to mode I, the charge and discharge positions of capacitors C_{i1} and C_{i2} in stages A, C and E are same during the first half cycle. The only difference is that current i_{c2} is less than i_{c1} in stage B during mode II operation as shown in Fig 4b, which is complement to that in operation mode I. The value of periods for stages B and D are a common value and is equal to $(D\text{-}D_c)$ $T_s/2$. For example, if $V_{c1}=V_{c2}=V_i/2$; C_{i1} will provide more energy to the load than C_{i2} in the first half cycle in mode II operation. Here also the situation in the second half cycle is common to first half cycle. Therefore, V_{c1} is less than V_{c2} in mode II operation as shown in Fig 4b.

Based on the above mentioned analysis, V_{c1} would be higher than V_{c2} in operation mode I, V_{c1} would be lesser than V_{c2} in operation mode II. A control strategy is proposed for the capacitor voltage balancing as shown in Fig 5. Where, a capacitor is used with two input voltages V_{c1} and $V_{c2.}$ If $V_{c1} > V_{c2}$, the mode of operation in the next half cycle is selected as II. On the other hand, the mode I operation is selected in the next half cycle when V_{c1} is less than V_{c2}.

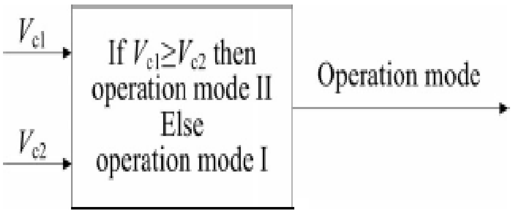


Fig.5 Block diagram of the proposed voltage balancing control for AFBTL DC-DC converter.

IV SIMULATION RESULTS

In this chapter, the simulation results obtained for the proposed system are given for 1KW output power. They are given for various parameters as shown below.

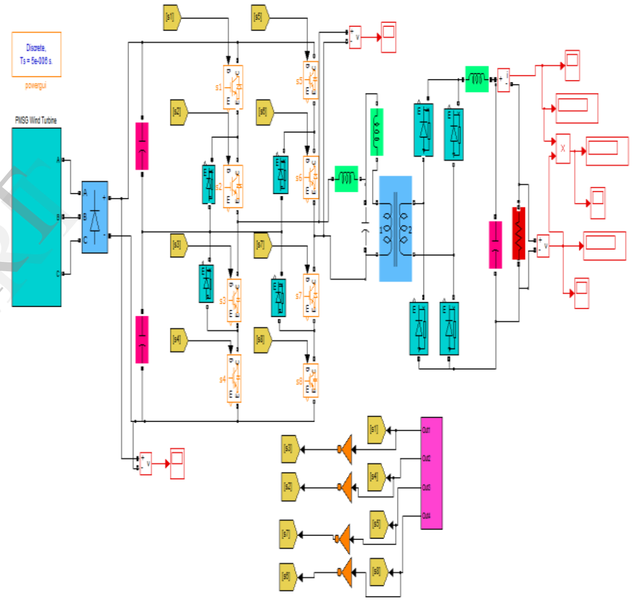


Fig.6. Simulation diagram for the proposed three leveled DC-DC converter configuration.

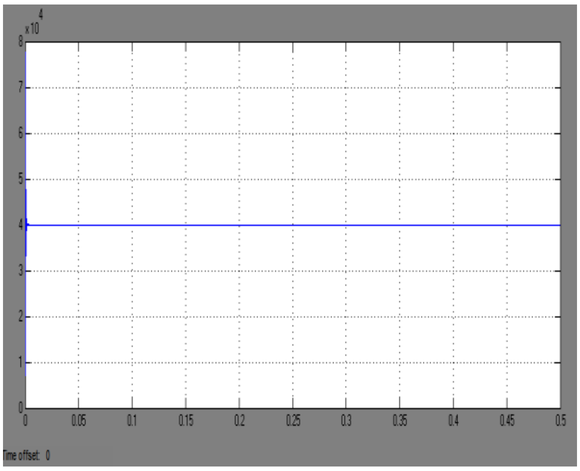


Fig.7. Basic Input voltage (V_i)

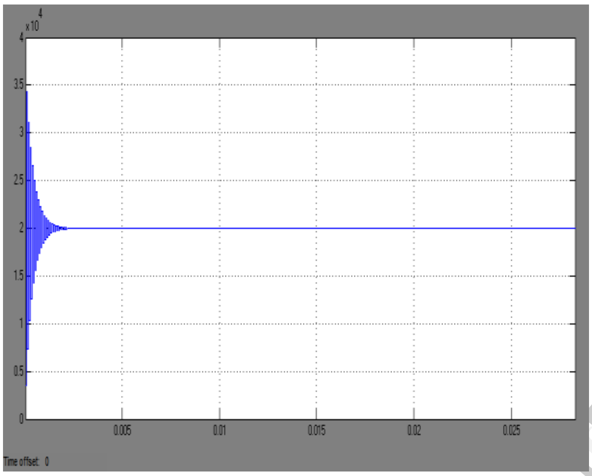


Fig 7. Voltage across the input capacitor C_1 (V_{c1})

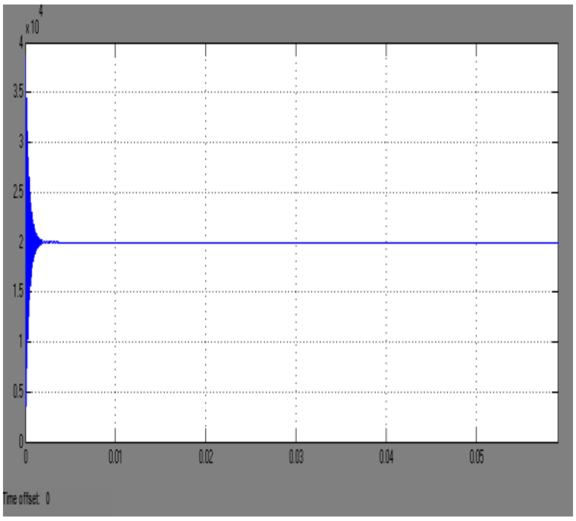


Fig. 8. Voltage sacross the input capacitor C_2 (V_{c2})

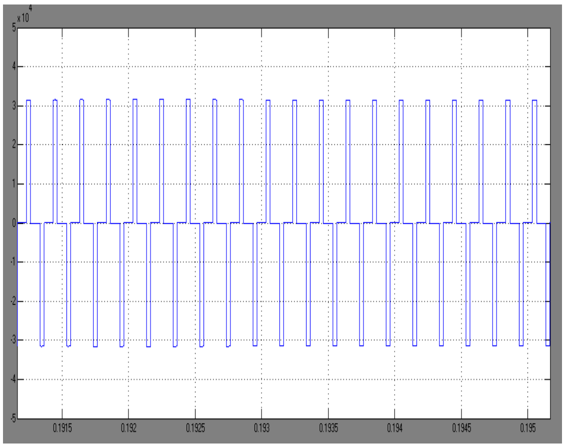


Fig.9. Output voltage obtained from the three leveled converter.

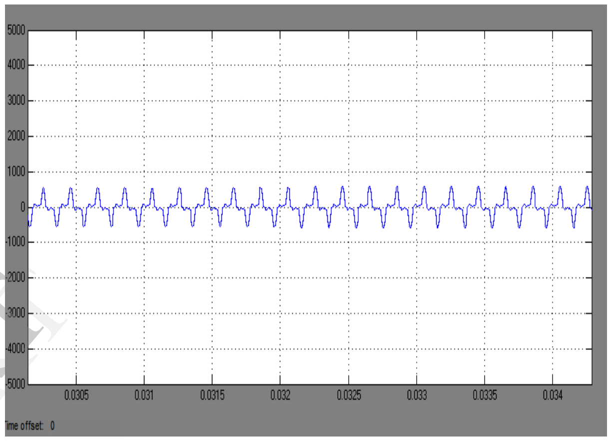


Fig.10. Transformer secondary winding voltage (V_{t2})

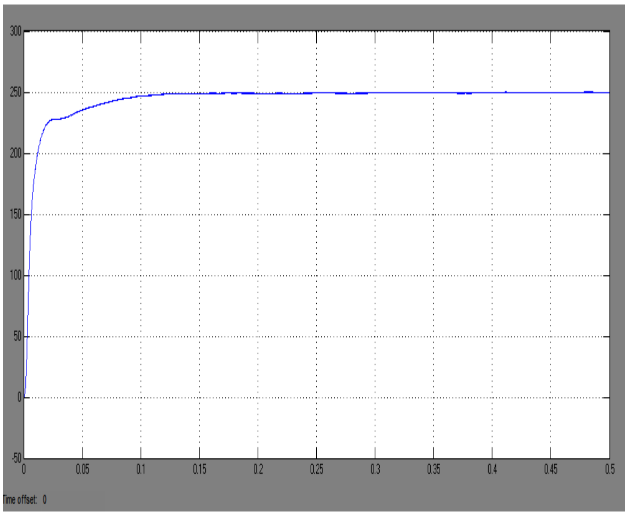


Fig.11. Load voltage (V_0)

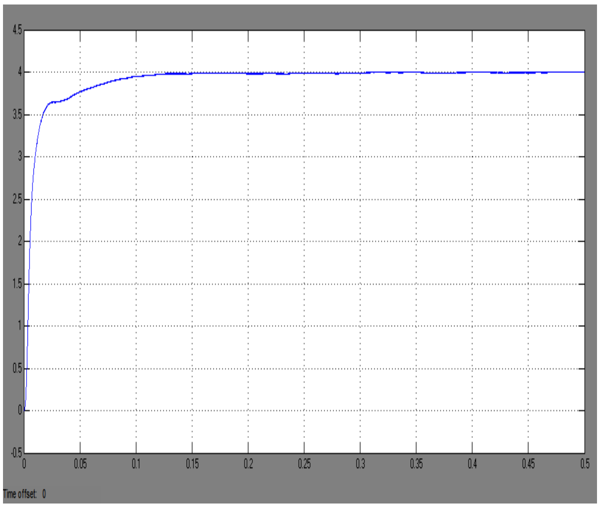


Fig.12. Load current (I_0)

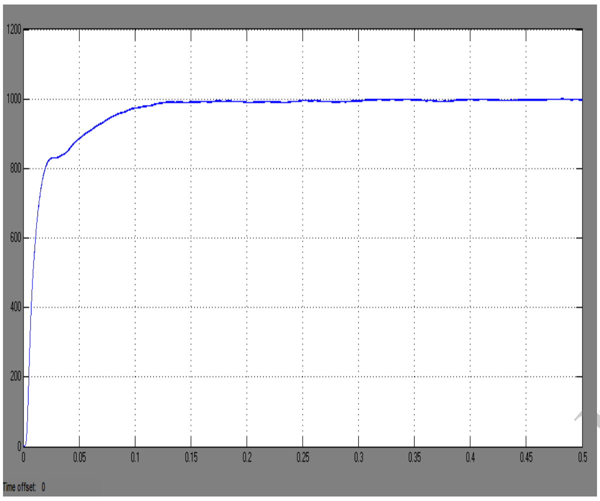


Fig.13. Delivered power to the load (P_0)

These are the results associated with the proposed three leveled DC-DC converter using voltage balance control technique. In this model, the voltage obtained from three leveled converter is given to the primary of transformer winding and then it is stepped down to an AC voltage as shown in Fig. 10. Finally the voltage obtained at the secondary can be inverted to DC in order to synchronize the DC grid. The magnitude of output power can be calculated from the product of output voltage and output current and from the simulation results it is clear for the 1KW output power configuration.

V CONCLUSION

This paper has presented the role of the AFBTL DC-DC converter for the wind power system. The modulation strategy with two operating modes I and II is proposed for the AFBTL DC-DC converter. The proposed operation modes I and II are discussed very clearly. A voltage balancing control technique is given for the proposed AFBTL DC-DC converter, where the alteration of mentioned operating modes can maintain the balanced capacitor voltage. With the use of modulation technique and passive filter, the voltage stress of the transformer is effectively reduced, which is very important in the medium voltage and high voltage applications. A simulation type of 1KW AFBTC DC-DC converter is tested and obtained good results for recommending it to the real time applications.

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