Multi Boost Voltage Impact on the BDFRM Equipped with SVPWM Inverter

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Abstract. **This paper investigate the boost voltage influence on the double fed cascade machine parameters during variable speed trajectory based emerging Brushless Doubly Fed Reluctance Machine BDFRM (Motoring Mod) which is classified as one of cascade machine construction. The adopted boost voltage in the secondary side machine recovers the lack of control voltage in secondary side of machine. The boost voltage in the double feed brushless machine need more consider a serious challenge for the researcher especially when it need to support positive and negative voltage sequentially. The solving this problem consider as Key evolution of theoretical control enhancement in the control algorithm to prevent the torque failure during sub speed mode and transient period. Scalar control is the first beneficiary control algorithm adopted new approach boost voltage as stiff and qualified control algorithm suggested to improve performance of variable speed control. The study should give clear motives to maintain the bipolar (±) Boost voltage for individual speed mod.**

Keywords: BDFRM; scalar control algorithm; boost voltage Enhancement

I. Introduction

The emerging BDFRM Machine considered a reliable and alternative solution to the existing Induction machine with limited speed alteration taking in account the capability to serve under renewable wind turbines and WECS application [1]. The competitive performance at low cost maintenance with relatively small inverter size is affording huge attention from power engineering researchers. Unlike the DFIG, which has the same brushless structure taking in account the further advantages corresponding with special silence rotor (gage less) and brushless design which minimize the brushes losses and increase the reliability, low maintenance and cost reductions. These can be particularly main advantages compared to DFIGs, which was earlier designed to work in WECS application [2].

According to the unique design of synchronous reluctance machine the stator contained two adjacent windings one is primary (power) winding, connected to the main supply and the secondary (control) winding is converter feeding through inverter. The both winding decoupled due the different pole numbers, surrounding a salient and non-winding 4-pole rotor [3] as shown in Fig. 1. The stator windings (p-primary and s-secondary) are magnetically coupled just in harmony with the rotating reluctance rotor, which makes this transaction possible. The number of rotor pols should become one-half of the total numbers of stator pols (primary and secondary) poles [4, 9].

One of the interesting properties of the BDFRM and the BDFIM are the multi-operational mode. They can run as a conventional induction machine by short-circuiting the secondary terminals, which might be an important solution to prevent in inverter failure when sustained operation would be possible. Thus the same operating mode adopted in start mod to prevent the inverter from the transient operating process. A second feature is the synchro-mode performance when the secondary winding already linked to the DC voltage. the BDFRM then is tracking the supply frequency as natural behavior to synchronous mode [5, 9] and the super-sub synchronous speed can be easily reached by linking the secondary (control) winding with low rated inverted which consider as the big advantage of the designing BDFRM.

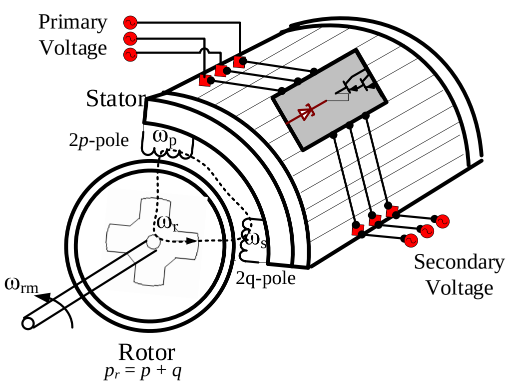


Fig. 1. BDFRM construction

The main target of this paper is evaluating the theory approach of adopting boost voltage and the advantages could be appears through operating multi-mode machine performance (induction, synchronous, (super-sub) synchronous speed). In addition, the different in boost voltage supply when it deals within slip recovery frequency when the synchronous frequency consider as throw should values between the positive and negative fed voltage. Evaluate the control theory with a valuable enhancement in term of using a boost voltage as motivating voltage to recover the failures in torque behaviours. These options will be tested consequently with multi mod speed allied with distinct observation in the following sections.

II. Main Reason to Implement Boost Voltage

There are many disadvantages associated the conventional scalar control algorithms especially when they dealing with systems that adopt the slip speed frequency. The BDFRM is the machine that built up in this domain as doubly fed voltage ,primary frequency and secondary frequency (slip frequency) [6]. The slip frequency can be achieved from Eq. (1). This relation specify the reference frame of scalar control and the phase different between the primary and secondary winding velocity:

$$\omega_s = \omega_r - \omega_p \tag{1}$$

When the rotating velocity in equation (1) reaches to the synchronous speed $\omega_r = \omega_p$ = 750 [rpm], the secondary slip frequency then decline to zero $\omega_s = 0$. This attitude adjusted by the basic equation of the essential secondary voltage, where the value of the secondary voltage depends on the multiplying conjoint flux field $\psi_{ps}$and secondary slip frequency in Eq. (2).

$$\underbrace{U_s}_{0}\downarrow = \underbrace{2\pi\psi_{ps}}_{\frac{V}{f}\text{ratio}} * \underbrace{(\pm\omega_s\downarrow)}_{0} \tag{2}$$

Therefore, the first concerning reason to adopt DC voltage appears in Eq. (2) when the secondary voltage descended to zero. Second reasons to implement threshold DC voltage, is motivating reluctances machine to drive in synchronous mod in this mode machine will get tracking with the desired or reference frequency to give control system additional capability to pass through the transient periods and to reach optimal speed capacity in sub or super synchronous mode. Third reason is involving offset DC voltage help recovers the obvious torque weakness when the speed equal sync-speed 750 [rpm] [7] . The boost voltage polarity follow the sign of slip frequency ($\pm\omega_s$) by value equal to 10% of the rated voltage U_p, according to the conventional V/f characteristic clarified in Fig. 2.

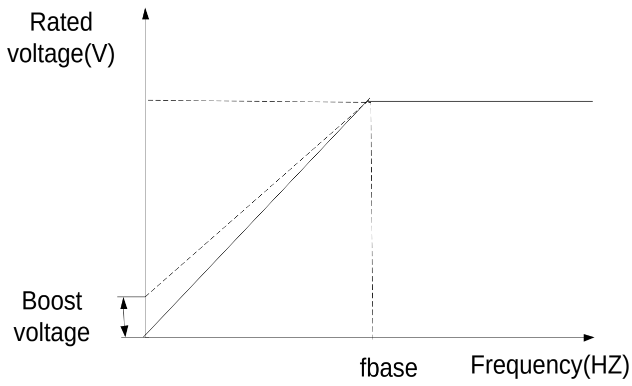


Fig. 2. V/f diagram offered 10% of rated voltage as boost voltage

III. Mathematical Confirmation of Boost Voltage Model

The theory of supporting voltages can be assigned mathematically according to the following equations, which are illustrating the secondary side voltage based dynamic model form of brushless doubly fed machine BDFRM. The maximum torque per ampere inverter already simplified the equations below by considering the current I_{sd} = 0 and maximising secondary reactive current I_{sq} as a torque producer .That's will provide the new adjustment to the secondary side formulations, started from the steady state condition of the secondary side voltage equations (3, 4).

$$U_s = R_s\underline{i}_s + \underbrace{\left[\frac{d\psi_s}{dt}\right]}_{0} + j\omega_s\lambda\underline{\psi}_s \tag{3}$$

$$U_s = R_s(i_{sd} + j\,i_{sq}) + j\omega_s\underline{\psi}_s \tag{4}$$

For maximizing torque effect, i_{sd} = 0 due unloaded machine circumstance:

$$U_s = j\,R_s i_{sq} + j\;\omega_s\left[\psi_{ps} + j\sigma L_s\frac{2T_e}{3p_r\;\psi_{ps}}\right] \tag{5}$$

$$U_s = j\,R_s i_{sq} + j\;\omega_s\psi_{ps} - \left[\underbrace{\sigma L_s\frac{2T_e}{3p_r\;\psi_{ps}}\omega_s}_{0}\right] \tag{6}$$

So the real portion in equation (5, 6) equal zero then the Eq. (7) justifies the urgent need to the threshold boost voltage as additional important part in the secondary voltage definition.

$$U_s = \underbrace{R_s i_{sq}}_{\text{Boost Voltage}} + \underbrace{2\pi\psi_{ps}}_{\frac{V}{f}\text{ratio}}\cdot(\pm\omega_s) \tag{7}$$

Hence the boost voltage is considering elaborate add to SC control algorithm as the threshold DC voltage to avoid disappearing essential voltage when slip frequency drop to zero.

IV. RESULTS AND DISCUSSION

These test results have been extracted by performing the SC algorithm in Fig. 3 at fixed frequency 5 kHz space-vector PWM [8] rate (i.e. the inverter switching frequency) and V/f ≈ 0.8 this ratio being calculated as suitable ratio to gate minimum copper losses. The half-loaded BDFRM machine capacity 1.5 [Kw], and its parameters mentioned in Table. 2 as a specific reference of this test. The simulation performance reflects the theoretical approach revealed earlier in the introduction a paragraph, which clarify the capability of the BDFRM machine to work in multi-mode operations and prove the impact of the Boost voltage during this modification. The half-loaded nine [Nm] machine gives an opportunity to evaluate the sequential speed behaviours during different synchronous mode. Starting from un pure induction machine mode by simply short circuiting the secondary winding Fig. 4 period (4–6) s Due the subtracting between T_e and positive T_L as motoring mode, the speed obviously appears lower 730 [rpm] than reference speed 750 [rpm] and torque achieve its level with alternative secondary currents the effect of boost voltage absence due $\omega_s = 0$. The dramatic change occurs in the second control period (6–8) the slight deviation occurs in slip frequency $\omega_s \neq 0$ enabled the dc boost voltage to take role and change the mode work to Synch-mode, so the speed in (b) return to follow reference speed 750 [rpm] synchronous speed (one of Synchronous-mode advantages) and that's justified the tendency of control enhancement to recover load effect and meet sync-speed 750 [rpm] again as it obviously appear in the second period and the torque keep the load level Fig 4 *c*. The flat current considers the main symptoms reflected the nature of the DC supply voltage shown in Fig.4 *d*.

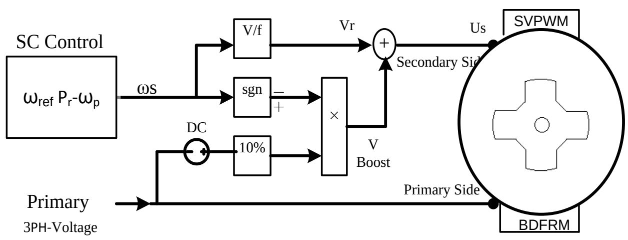
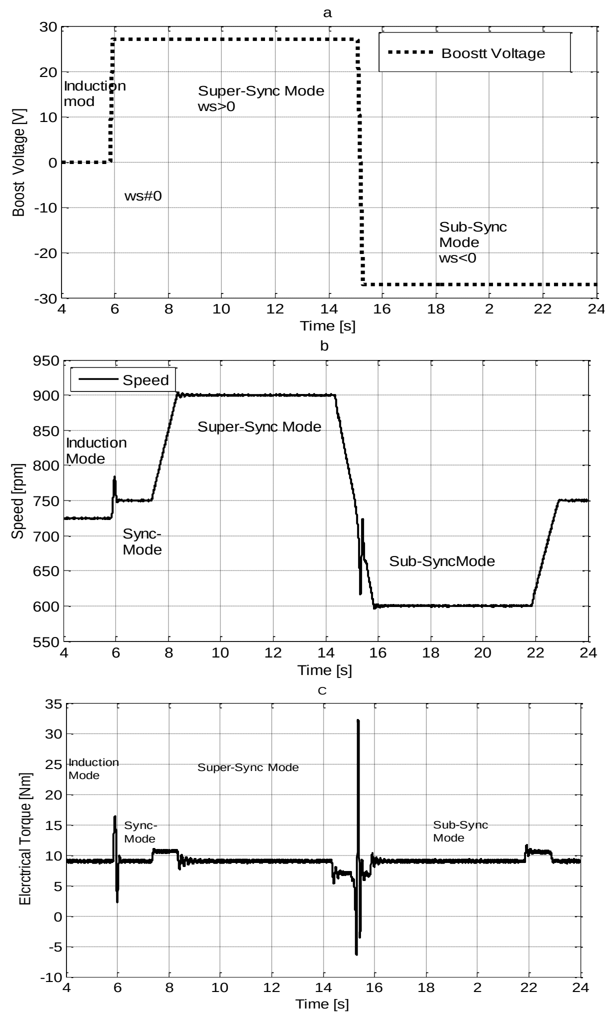


Fig. 3. Configuration of scalar control associated with boost voltage unit

The third period (8–14) s reflect the behaviour of machine during supper sync-speed when the secondary side of machine affected by two voltages. First is the main alternative voltage and the second continues DC boost voltage (the control side of machine still fed DC voltage secondary side of machine whenever the slip frequency not equal zero, according to pre-design Fig. 3. On the other hand, the increase of slip frequency magnitude to allow the alternative voltage to growth gradually and inforce the machine to reach super synchronous speed 900 [rpm]. The rapid change boost voltage change the polarity to the negative voltage a combined with decline speed from super to sub sync-speed will effected the system stability so the sharp glitches appears in speed behaviour, torque and phase current as well Fig 4 *a, b, c*. This period can clearly be stated as a transient period (14–16) s. The swiping of voltage polarity is helping machine to change the speed mode correlating with the negative slip frequency (-ωs). The DC voltage disappear again when the speed passing through concerning synchronous speed (ωs = 0) and build beyond it negative overflow and force the machine to act in sub synchronous mode period (16–22) s Fig. 4. The sub synchronous control period will start to perform his own features by changing the phase sequence of secondary current, the speed will descend under synchronous speed to reach 600 [rpm] with negative DC voltage motivation and the torque still achieve the same level even with subtracting of the positive load torque vs negative voltage supply that will cost the machine to spend more secondary currents to achieve same torque performance.

TABLE I. THE SLIP- FREQUENCY MODES

Secondary Slip frequency	Mod Operation	Speed Mode
ω_s>0	Super Synch-Mode	Super-Sync-Speed > 750 to 1000 [rpm]
ω_s<0	Sub sync-mode	Sub-Sync-Speed < 750 to 500 [rpm]



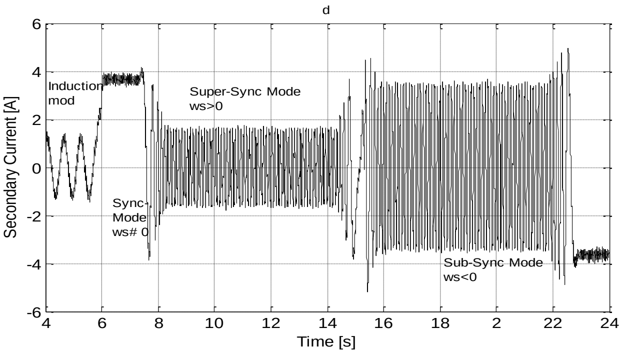


Fig. 4. The effect on (a) boost voltage, (b) speed, (c) torque, and (d) secondary current

TABLE II. THE PARAMETER OF BDFRM 1.5 KW USED IN EVALUATING MACHINE

Labels	Parameters Values	Definition
f_p	50	Grid Frequency [Hz]
V_p	380	Primary voltage (rms) [V]
P_r	4	Rotor Poles
J	0.1	Rotor inertia [kgm^2]
R_p	11.1	Primary winding resistance [Ω]
R_s	13.5	Secondary winding resistance [Ω]
L_p	0.41	Primary winding inductance [H]
L_s	0.57	Secondary winding inductance [H]
$L_{ps} = L_m$	0.32	Mutual inductance [H]

Finally, our investigation has verified the boost voltage advantages to improve the machine performance during speed swapping from level to level under different mod conditions. Therefore, it has enhanced the control stability through transient period in which the voltage of the boost voltage changes from positive to negative polarization. The SC control is working properly following the variable slip frequency. The factor such as boost voltage enhanced the simple construction control to respond to desired and help the researchers to implement this basic approach in the futures work.

V. CONCLUSION

We have properly demonstrated the possibility of SC control based BDFRM to drive variable speed supported with the boost voltage linked with alternative slip frequency polarity as a control outcome. Finally, our investigation has verified the boost voltage role to increase the machine flexibility during swapping from super to sub-synchronous speed under different mod conditions. So it has further enhancement to achieve control stability through transient period in which the boost voltage help to change the state from positive to negative polarization recovering the transient and enhanced the simple sensor less control construction to much high-performance control algorithms which's entail classy requirements, and helps the researchers to adopt this basic approach in the futures work.

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