STUDY ON ENERGY EFFICIENCY AND HARMONICS MITIGATION IN A HVAC AHU BLOWER/FAN APPLICATION USING ELECTRONICALLY COMMUTATED BLDC MOTORS

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Abstract—Air Handling Unit (AHU) Blowers in a Heating Ventilation and Air Conditioning (HVAC) system contributes to signification share in the total energy of a typical commercial establishment. Energy efficiency projects in these AHU's widely uses speed control of motors with solid state devices. This method has a disadvantage of injecting harmonics in the system. Hence, this paper proposes a novel scheme of mitigating harmonics in an energy efficient way of replacing widely popular centrifugal blower driven by AC Induction motor connected to Pulse Width Modulation (PWM) based Variable Speed Drive(VSD) with a variable speed Electronically Commutated Brushless DC radial blowers (EC BLDC). Comparisons based on simulation and theoretical analysis using Matlab / Simulink of the proposed scheme is validated by a real time retrofit with an EC BLDC radial blower in a AHU which was originally fitted with a centrifugal blower driven by AC Induction motor connected to a PWM based VSD. The results of the study achieved a reduction in Total Harmonic Distortion (THD) by 15 % and reduction in energy consumption by 40 %. Further the proposed scheme opens up future opportunities for improving the overall system efficiency by optimizing the selection and installation of EC BLDC blowers after performing aerodynamic analysis of the AHU.

Key words: HVAC, AHU, BLDC, Energy efficiency, Harmonics mitigation.

1. INTRODUCTION

HVAC (Heating Ventilation and Air Condition) contributes to 30 to 35 % of the total energy expenditure in any industrial and commercial building. Air Handling Unit (AHU) is an integral part of HVAC systems. Electrical motor driven fan of an AHU consumes 8 to 10 % of the total energy consumed [1]. Reduction in energy consumption through speed control is a commonly used technique in Variable Frequency Drive (VFD) to feed Induction Motor (IM) driven fans. The losses incurred in these fans are comparatively high and also, the range of speed modulation is set low, in a range of 60 % to 100% , with reference to the Iso efficiency curves of the IM centrifugal Fan. But, for personal comfort and higher efficiency, wide range of speed control in fans is needed in the AHU of a typical HVAC system. Technological advancements in the fields of power electronics, electronic commutation systems makes Brush Less Direct Current (BLDC) motor design highly suitable for wide range of speed control for AHUs. Retrofitting an existing AHU with VSD fed IM fan with BLDC EC Fan has also been made possible due the smaller form factor of EC BLDC fans. Such a retrofitting of AHU also provides an additional benefit of downsizing the fan capacity based on accurate specifications such as flow and static pressure.

In the proposed work, an attempt is made to perform an energy efficiency retrofit in a manufacturing industry in which the HVAC was used for precision machining. In this paper, Section 2 describes the different modes of VSD fed IM based AHU operation typically used in industries and its shortcomings. Section 3 presents the technical characteristics of BLDC EC fan and the advantages of using them in Air Handling Units. Section 4 presents the simulated results of VSD fed IM driven fan and BLDC EC fan of the proposed setup. Section 5 presents the real time results of proposed methodology and discusses the tangible benefits of the real time data acquired using power analyzers capable of measuring the various losses. Section 6 presents the future scope of the proposed work that includes safety interlocks, reliability and Computational Fluid Dynamic analysis to improve the reliability of the achieved results. Also, suggestions on possible reduction of harmonics in BLDC EC fan through filter parameters is briefly presented.

2. INEFFICIENCIES OF AHU WITH VSD FED IM DRIVEN CENTRIFUGAL FANS

The capacity of a typical HVAC system is designed based on peak load conditions, with assumptions on design variables such as peak occupancy, ambient temperature, and equipment / lighting load. These variables are observed to be constantly changing throughout the day. In such situations, the system might become unstable in the absence of proper control system and eventually the HVAC would either overheat or overcool the spaces. According to AHRI Standard, the HVAC system will be at full load condition only one percent of the operating time of in an entire day, which necessitates the improvement in part load efficiency of each component of the HVAC for achieving higher overall efficiency.

In majority of the AHU control schemes, the speed and flow rate of supply air and return air from fan is varied as a function of temperature that is maintained in the delivery duct. The typical control schemes are depicted in figure 1 and figure 2. Schemes may have closed loop speed control as a function of static pressure of the shop floor or as a cascade closed loop control based on temperature and static pressure. In certain schemes such as variable air volume box is used, part load efficiency of the blowers play a vital role in the overall efficiency of the system.

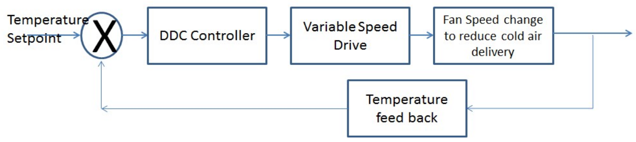

Fig. 1. Closed loop Control of VSD fed IM driven fan based on temperature

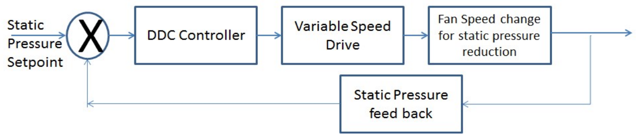

Fig. 2. Closed loop Control of VSD fed IM driven fan based on static pressure

The challenge in the above mentioned schemes is the efficiency loss due to IM driven centrifugal fans that are present in AHU of a typical HVAC system. Figure 3 illustrates the losses (red arrows) that occur in the various stages of the electrical system of a VFD driven Induction Motor. From literature, it is observed that the electrical losses constitutes 3 to 5 % [2] of the input power due to the components such as EMC filters, Line Filters, Inverter and Motor filter.

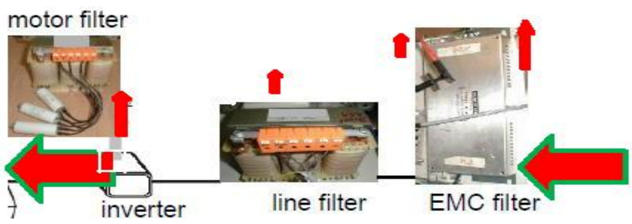

Fig. 3.SanKey Diagram of Induction Motor VFD Electrical Circuit

In addition to the losses due to power electronic components, electro mechanical losses also arise in the induction motor and fan assembly such as motor losses, belt drive loss and losses due to turbulence inside the casing of the fan. These losses are illustrated in the Figure 4 Sankey diagram (gray arrows).

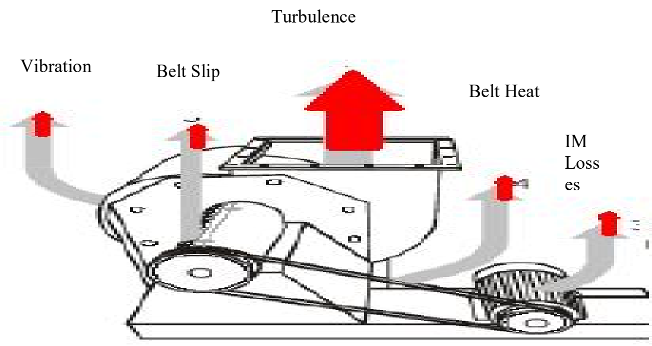

Fig. 4. Losses in a IM driven centrifugal fan of an AHU

3. ADVANTAGES OF BLDC EC MOTOR FAN BASED AHU

BLDC EC fans driven by electronic commutation [3] are commercially available at capacities less than 4 KW and are practically deployed as a matrix of fans to achieve higher flow rates and static pressure. The reliability of the system gets improved due to this matrix arrangement since the failure of a single fan would not affect the system. This reliability is not possible in a single fan VSD fed IM driven fan. In addition, the BLDC EC motors is of lesser capacity, hence they do not require EMC filters, Line Filters, Inverter and Motor filter. This leads to the reduction in losses encountered in the control scheme.

Since the BLDC fans are of axial type and direct coupled with motor, the electro mechanical losses such as belt slippage are totally eliminated. The turbulence losses are also reduced to a greater extent due to the aero dynamical fitting of the motor in the hub of the fan. Reduced electrical losses are reported due to the permanent magnet rotor as compared to a wound / squirrel cage rotor of an Induction Motor which contributes to the rotor I^2R loss.

The optimal efficiency of a VSD fed IM driven centrifugal fan ranges from 60 to 100 %. For speeds lesser than 50% of the rated speed, efficiency of the fan drops to 57% as observed from Figure 5. This disadvantage makes VSD fed IM driven Fan inefficient for wide range speed / flow modulation application using a closed loop control system. DC brushless motor generates reduced rotor heat due to the permanent magnet rotor usage. This reduction in heat from rotor also decreases the inherent load to the HVAC system. Rotor cooling can be easily performed and the peak point efficiency is observed to be high for this drive.

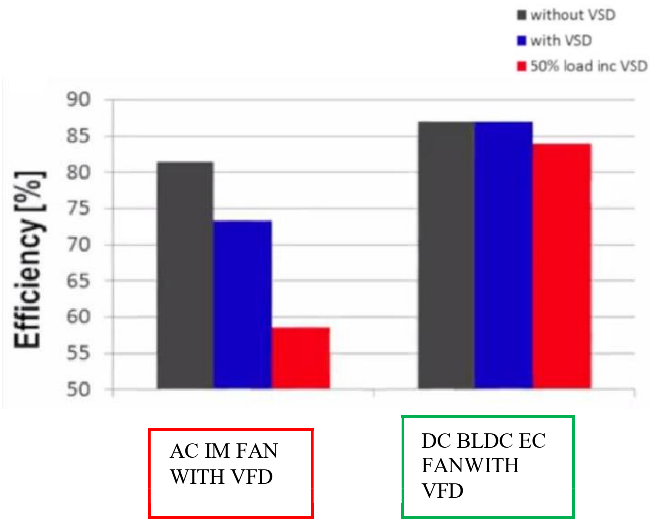

Fig. 5. Comparison of Efficiency of an AC IM FAN with VFD & DC BLDC EC Fan with VFD [4]

The brushless DC drive can also operate at unity power factor, while the maximum power factor of induction drive is 0.85. This infers that the peak point energy efficiency of a DC brushless drive will typically be a few percentage points higher than for an induction drive. Stability in Speed could be achieved using Hall effect sensors built in the BLDC motor that detects the change in polarity from a north pole to a south pole as the rotor is spinning. The speed of the rotor is determined by the time between state changes [5]. This measurement is reported to be highly precise in comparison to the speed derived from a IM VSD.

4. SIMULATION AND THEORETICAL ANALYSIS USING MATLAB SIMULINK

This section reports the results of theoretical analysis performed using electrical models built using Matlab Simulink software. Models of VSD fed Induction Motor and BLDC EC drive with both filter and without filter were designed. The Simulink model of the PWM VSD fed IM is depicted in figure 6 and BLDC EC drive without filter is shown in figure 7. Figures 8 and 9 presents the FFT analysis results of the simulated current waveform equal to the capacity of selection. Rotor position of the BLDC is sensed by Hall Effect sensor which generates pulses to the inverter to drive the motor. The whole system was fed from a 3ø voltage source. The three phase line current and voltages were measured.

From figures 8 and 9, it is inferred that the Total Harmonic Distortion (THD) due to IM drive is approximately 45% while BLDC EC fan is approximately 32%. This shows the significantly reduced THD achieved using BLDC EC fan.

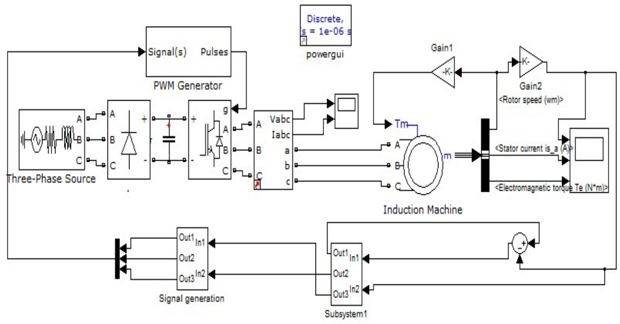

Fig. 6. Simulink Model of PWM VSD driven IM

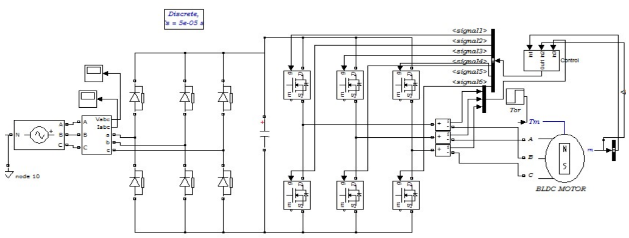

Fig. 7. Simulink Model of the BLDC EC drive

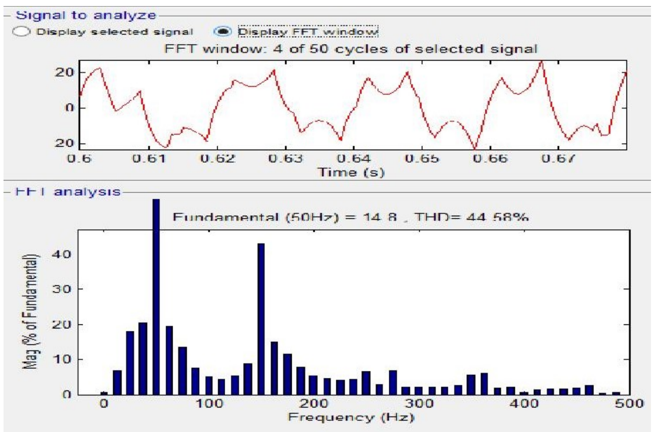

Fig. 8. FFT analysis of the current waveform of PWM VSD of IM

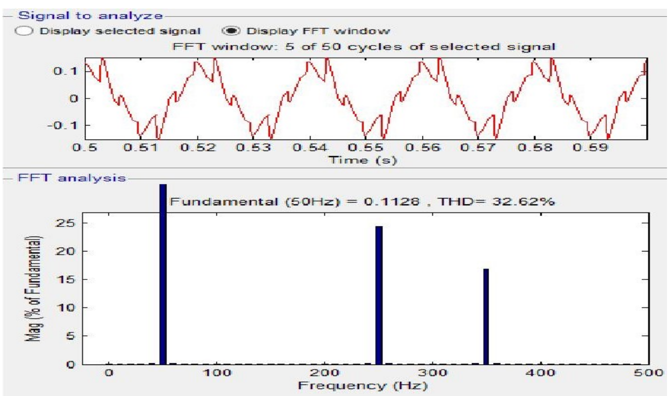

Fig.9. FFT analysis of the current waveform of ECBLDC drive (without filter)

5. REAL TIME RESULTS AND DISCUSSION

The images of the real time experimental setup in which an Air Handling Unit with VSD fed IM driven centrifugal fan is retrofitted with EC BLDC motor fan are shown in Figure 10.

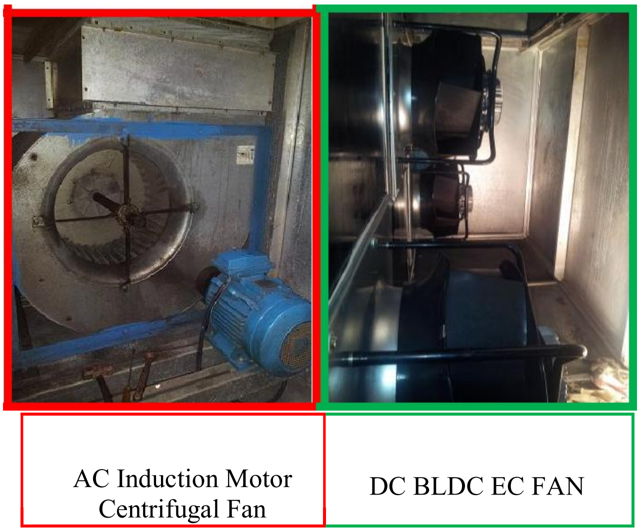

Fig. 10.Real time Images of an AC IM Centrifugal Fan & DC BLDC EC Fan

Table 1 presents the specifications of the AC IM Centrifugal fan versus the BLDC EC fan. As observed from table 1, the static pressure requirement of IM is low as 140 pascal at a flow rate of 48229 CMH. For similar mechanical parameters, when an EC BLDC fan is selected, it had electrical specification of 2.25 KW input power in comparison with 14.5 KW of a centrifugal blower with IM. This considerable change in power requirement may be attributed to the over design during the design stage of the building or advancement in latest air conveying technology such as the EC radial fan.

TABLE 1. COMPARISON OF AN AC IM CENTRIFUGALFAN& DC BLDC EC FAN

Parameter	Supply air blower (Induction Motor)	Supply air blower (BLDC EC Motor)
Voltage	404 VAC	404 VAC
Frequency	50 Hz	50/60 Hz
Current	31 A	3.8 A
Input power	14.5 kW	2.25 Kw
Airflow	48229 CMH	48357 CMH
Static Pressure	140 Pascal	147 Pascal
Number of Blower	1	5

Table 2 compares the specifications of IM centrifugal fan and BLDC axial fan based on the return air from blowers. The mechanical parameters of return power is higher than the supply air due to the altitude of the return air duct and two stage filtration involving grease and dust filter in its suction. IM requires 41339 CMH at 535 pascal while EC BLDC radial fan comparatively consumed 4.7 KW against 15.8 KW of IM driven centrifugal fan.

TABLE 2. SPECIFICATION COMPARISON OF AN AC IM CENTRIFUGAL FAN& DC BLDC EC RADIAL FAN

Parameter	Return air blower (Induction Motor)	Return air blower (BLDC EC Motor)
Voltage	404 VAC	404 VAC
Frequency	50 Hz	50/60 Hz
Current	27 A	7.6 A
Input power	15.8 kW	4.7 kW
Airflow	41339 CMH	42156 CMH
Static Pressure	535 Pascal	542 Pascal
Number of Blower	1	5

From tables 1 and 2, it is learnt that the use of BLDC EC fan could achieve an energy saving of 50 to 70 %. This saving can further be increased by modulation using [7] Programmable Logic Controller (PLC) or electronic controller.

TABLE.3. COMPARISON OF POWER CONSUMPTION OF AC MOTOR WITH CENTRIFUGAL FAN AND EC BLDC RADIAL FAN

Description	BEFORE AC IM Centrifugal fan Power consumption in one AHU	AFTER EC Fan power consumption in one AHU
Air Handling Unit	30.39 kW	7.1 kW
Net Energy Saving	23.29 KW	

From the results, it is seen that a power saving of 23.29 KW was achieved as a result of this retrofitting exercise from AC motor driven centrifugal fan with BLDC EC radial fan.

The real time data were measured using Fluke Class A Power Quality Analyzer [6]. Figures 11 and 12 show the real time Energy loss estimation before and after the proposed retrofit scheme. Figure 12 shows the reduction of effective power from 30.3 KW to 7.13 KW and Distortion losses from 11.3 KVA to 2.87 KVA after the retrofit. It is clearly observed from the power log software [8] estimation that the total losses incurred is reduced in case of the existing BLDC EC motor.

Fig. 11. Data from VSD fed IM through power quality analyzer with power log software BEFORE retrofit

Fig. 12. Data from BLDC EC fanthrough power quality analyzer with power log software AFTER retrofit

The simulated and real time results discussed in this section presents the scope of reduction in energy consumption through retrofit of an AHU with BLDC EC fan. It is estimated that the proposed retrofit scheme will have a payback of 2 years. Table 4 shows the simplified payback calculation.

Table 4 Simple Payback Calculation

Cost of one EC BLDC Fan	2700 Euro
Cost of 10 EC BLDC Fan for 1 AHU	27000 Euro
Saving in KWH for one AHU / Hr by retrofit with EC BLDC fan	23.29 KWH / Hr
for 20 Hours operation in a day	465 KWH / day
For 300 days operation	139740 KWH / year
Cost saving in INR per year	887349 INR / year
Cost saving in euro per year @ INR 75 / euro	11831 Euro
Pay back	**2 Years**

6. CONCLUSION AND FUTURE SCOPE

On performing an overall analysis of the proposed scheme, it is found that there is scope for further improvement in the electrical and mechanical control schemes. The harmonic level could be further reduced by employing a filter with inductor value of 0.33mH and capacitor of 1µF as shown in Figure 13. The simulated results after addition of the filter are shown in figure 14.

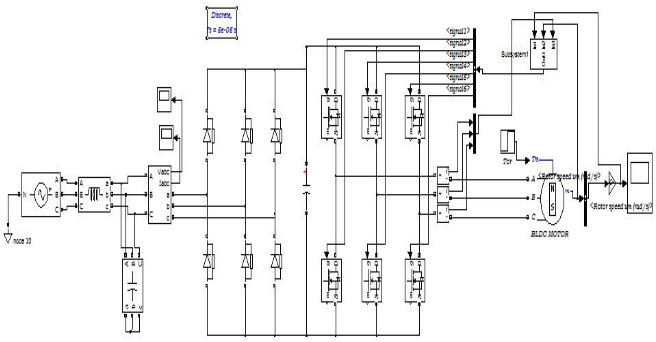

Fig.13. Simulink Model of the BLDC EC drive with filter

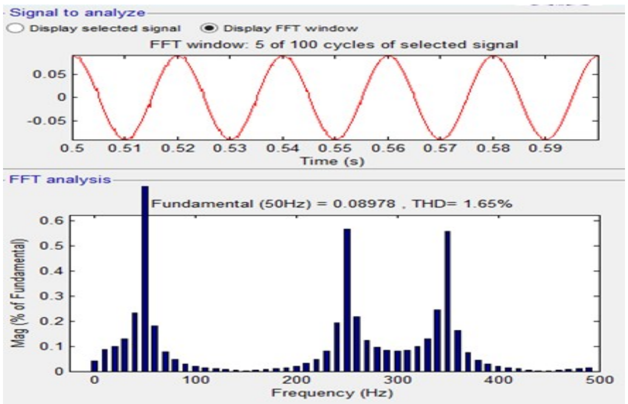

Fig 14. FFT analysis of the current waveform of EC BLDC drive (with filter)

Due to the form factor and the matrix design of BLDC EC fans, void areas exist that leads to generation of eddies during flow of air and thus results in velocity loss [9]. BLDC EC radial fans are quiet in comparison to one single centrifugal blower with belt drive. This reduces the need for noise attenuation components in the AHUs that results in further reduction of back pressure to the flow of the fan. These mechanical modifications need careful computation of fluid dynamics for optimum design.

For further improvement of the proposed scheme, the in-built controllers of the EC BLDC fan could be monitored from remote sites using MODBUS based data logging system and integrated with plant building management system.

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