Review paper on the control system of the air handling units

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Abstract- *This paper focuses on the study of different control strategies of Air Handling Unit and also the power saving techniques. As energy performance of the system strongly depends on the selection of heating, ventilation, and air-conditioning (HVAC) system configuration as HVAC systems account for approximately 30 - 60% of the total energy consumption. Variable frequency drives are nowadays a key manner for lowering the consumption of the HVAC system in peak time. In this paper different types of variable frequency drives, their operations, methods of controlling speed, challenges faced during implementation of VFD and power saving techniques are discussed.*

Key words: *Air handling unit, control strategies, VFD, HVAC.*

1. INTRODUCTION:

The system requirements are lower than the full capacity of Air Handling Unit (AHU), the cutdown energy cost can be done by using variable frequency drive for controlling the motor of the blower, Variable frequency drives allow to match the speed of the motor driven equipment. There is no other method of AC electric motor control that accomplish this. Nowadays electric motors in industry consume more than 65 % of power, optimizing control system by putting in or upgrading of VFDs will cut back energy consumption in the facility by the maximum amount like 70%. Additionally, the utilization of VFDs improves performance and reduces production costs.

A Variable Frequency Drive (VFD) can control the motor by varying the frequency and voltage supplied to an electric motor. VFD drives also known as variable speed drive, adjustable speed drive, adjustable frequency drive, AC drive, microdrive, and inverter.

Frequency (or hertz) is directly related to the motor's speed (RPMs). In other words, the higher the frequency, the higher the RPMs go. If an application does not require an electric motor to run at full speed, the VFD can be used to lower down the frequency and voltage as per load requirement. As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement.

To understanding the basic principles behind VFD operation requires understanding three basic sections of VFD: The Rectifier unit, DC Bus and the Inverter unit.

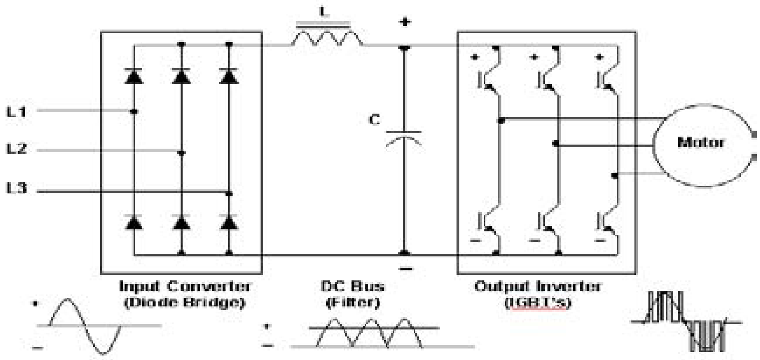


Fig.1 Circuit Diagram of Variable Frequency Drive (VFD) [1]

Rectifier units convert supply voltage into AC to DC supply, three phases full wave diode fed the three-phase supply where it gets converts into DC supply. In DC bus filter section is provided which filtered out harmonics generated during the AC to DC conversion. The third section comprises of inverter section which comprises with six IGBT (Insulated Gate Bipolar Transistor) where the filtered DC supply is being converted to a quasi-sinusoidal wave of AC supply which is supply to the induction motor connected to it. As we know that the synchronous speed of the motor (rpm) is dependent upon frequency. Therefore, by varying the frequency of the power supply through VFD we can control the synchronous motor speed:

$$\text{Speed(rpm)} = \frac{\text{Frequency(hertz)} \times 120}{\text{No of poles}}$$

Where;

Frequency = Electrical Frequency of the power supply in Hz.

No. of Poles = Number of electrical poles in the motor stator. Thus, we can conveniently adjust the speed of a motor by changing the frequency applied to the motor. By changing the no of poles the speeds of the motor can be also changed, but this change would be a physical change of the motor. As the drive provides the frequency and voltage of output necessary to change the speed of a motor, this is done through Pulse Width Modulation Drives. Pulse width modulation (PWM) inverter produces pulses of varying widths which are combined to build the required waveform. As the frequency can easily variable as compared with the poles of the motor, therefore, speed control drive is termed as Variable Frequency Drive (VFD) [1].

2.FAN HOUSING OF VARIABLE FREQUENCY DRIVE

Garron K Morris et. al. did research on "Driving energy efficiency with design optimization of a centrifugal fan housing system for variable frequency drive". In this paper details the modelling, design optimization, and experimental verification approach used to optimize blower housing designs for variable speed drives. The design of the blower housing is just as important as the blower selection. The existing housing can be controlled by modifying the housing dimensions, the shape and the quantity of flow. First, the impeller and inlet ring geometry were directly imported into Icepak from a CAD model provided by the manufacturer. For an accurate representation of the air flow, moving Reference Frame and multi-level meshing techniques were used. Next, a flow-pressure curve was created by varying the outlet pressure. The blower performance curve was found to follow, but consistently under-predict the empirical fan curve data given by the manufacturer. A model fan speed that was 2.4% higher than the operating speed was found to make the predicted by using fan laws and a multi-objective optimization approach, and manufacturer performance data agree with less than a 3% error. Then, using the tuned blower model and icepak software a parametric model of the blower housing was created. For these four parametric variables are chosen which includes the distance from the impeller to the front, bottom, side, and back of the housing was chosen. To extract the effect of outlet pressure on flow, the pressure was chosen as the fifth variable.

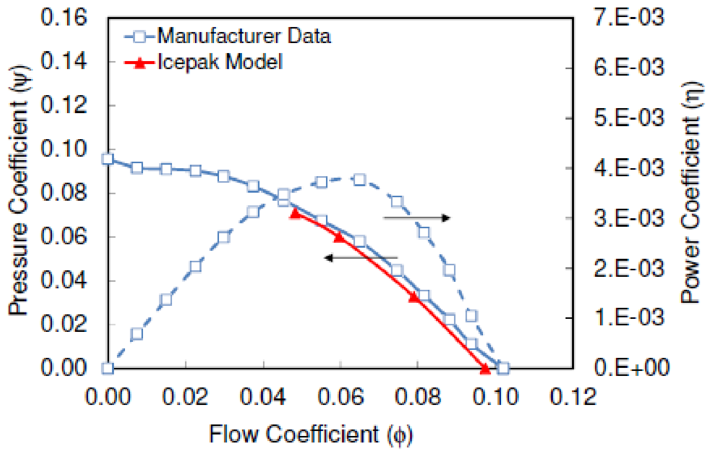


Fig.2 Fan performance is consistently under-predicted by the Icepak Moving Reference Frame model [2].

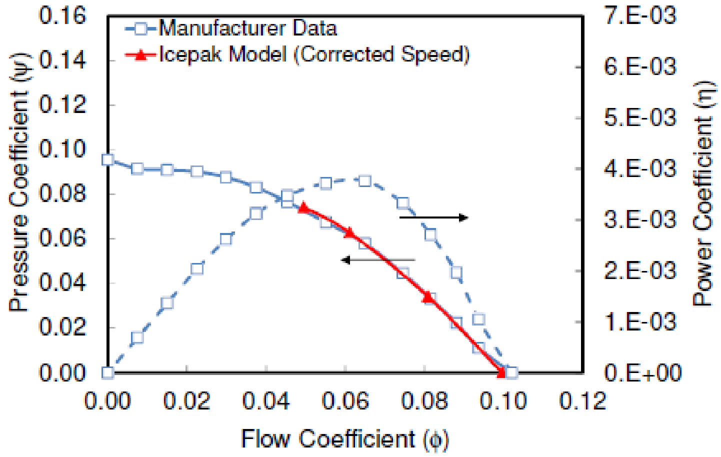


Fig 3. Predicted fan performance is in excellent agreement with manufacturer data after a 2.4% speed increase in the model [2].

The blower housing was optimized using a Design of Experiments (DoE) technique where the geometry of housing was varied in a structured manner to capture expected second order behaviour. The 27-run DoE was performed in Icepak and the volumetric flow through discretized portions of the outlet was recorded. The DoE data for each section of the outlet were fit to equations using a backward regression technique. A genetic algorithm-based optimization technique was used to create housing designs for two different variable frequency drives. For each design and flow-pressure curves prototypes of the housings were constructed for three samples of each design were measured on a flow bench. The measured curves were found to agree with the predicted blower performance in each housing design to within 7%. Design curves that could be used for other housings were also generated [2].

3.AHU CONTROL STRATEGIES

Yuying Sun et. al. did research on "AHU control strategies in the VAV system". In this paper mainly introduces Air Handling Unit control in the Variable Air Volume air condition system. The VAV control system includes three levels: the temperature control loop of the VAV BOX, the control of AHU; networking control of building automation system. This paper mainly introduces the AHU control and focuses on the similarities and differences of AHU control in the Variable Air Volume air conditioning system and the Constant Air Volume air conditioning system. It introduces some experiences of supply air temperature control of AHU and makes a comparison with the constant static pressure control strategy, the optimized static pressure control strategy, and the total air volume control strategy, to give some recommendations for the VAV system control.

Table 1. Advantages and disadvantages of three fan frequency control strategies compared [1]

Fan Control strategies	Control type	energy conservation effects	Advantages	Disadvantages	Requirements of BOX and BA system	Market ratio
Constant Static pressure control	Feedback control	40~50%	Simple control	Less energy-efficient	-	87%
optimized Static pressure control	Feedback control	50~60%	most energy-efficient	complicated Control	On line control, Need VAVBOX damper position feedback.	10%
total air volume control	Feedforward control	45~55%	fast Control respond	complicated Control	On line control, Pressure-independent VAVBOX, air flow measurement accuracy requirements	3%

This paper concludes that constant static pressure control, optimized static pressure control and total air volume control are all effective to the fan frequency regulation in the VAV system. Characteristics and differences between the three are as follows: the constant static pressure control is simple but less effective on energy conservation; the optimized static pressure control is the most energy-efficient, but too complicated and the VAVBOX must be networked; the total air volume control is found between the two in energy saving aspect, with VAVBOX networking and air flow measurement accuracy requirements. On fully considering on the different characteristics of VAV systems, BOX product performance, the owners demand and property management level, a reasonable selection of strategies and PID control parameters can provide the system with a stable and excellent operation [2].

4. VARIABLE FREQUENCY DRIVE AND ITS ENERGY SAVING

Tamal Aditya et. al. did research on "Research to study variable frequency drive and its energy saving". In this paper the working principle of Variable Frequency Drive. The performance of VFD is also described. The simulation model is simulated using MATLAB Simulink and their results are also analysed. The Total Harmonic Distortion (THD) in waveforms is also analysed. In the field of HVAC applications, the use of Variable Frequency Drive has been increased dramatically. Air handler, chiller, pumps and tower fans are some common applications of VFDs are in HVAC. By understanding of Variable Frequency Drives with leads to improvements in application and selection of both equipment and HVAC system. The main focus of this paper to provide a basic understanding of VFD terms, VFD operations and Power Factor improvement, Harmonics mitigation by VFD and a simulation project to show how VFD is beneficial for energy savings.

The simulation result is being calculated from a 4 pole Asynchronous motor of 3 HP and the Harmonics analysis using FFT tool of simulation of maximum frequency 5000 Hz.

Table 2. Data analysis of Frequency [1]

Fundamental Frequency	*Speed (RPM)*	*Order of Harmonics*	*THD of Voltage*	*THD of Current*
80	2400	62.5(even)	106.25%	30.49%
75	2250	66.66(even)	81.86%	19.65%
70	2100	71.42(odd)	67.89%	14.91%
65	1950	76.92(even)	55.46%	12.20%
60	1800	83.33(odd)	78.59%	11.46%
55	1650	90.90(even)	55.85%	18.72%
50	1500	100(even)	76.85%	32.86%
45	1350	111.11(odd)	126.29%	37.35%

It is clear that THD (V) level increases with as the value of fundamental frequency increases from 70Hz and also the fundamental frequency decreases 45 Hz or below. Therefore, fundamental frequency variations range should be kept in between 70 to 45 Hz. Due to the of the presence of ODD Harmonics in the frequency 70Hz, 60Hz and 45Hz the values of THD (V) is quite high as compared to other frequency presents in between them, as we know that the ODD harmonics is more harmful for the promotion of Distortion in the circuit than the EVEN Harmonics. It is easy to calculate the order of Harmonics as the maximum frequency is set as 5000Hz. Thus, the consumption of electrical energy is depending on the load requirement. However, the harmonics distortion can occur due to the variation of frequency which can be mitigated by several techniques of harmonics mitigation.

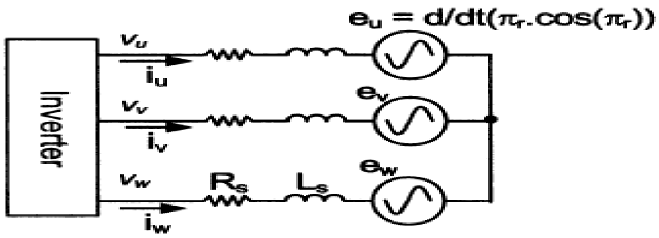
Thus, from the analysis of table, it is clear that as the speed decreases the Total Harmonics Distortion in voltage as well as in current increases and THD in voltage is lower than THD in current also the frequency variation leads to the harmonics change in the machine. Too much variation in frequency also leads to an increase in the THD voltage as well as THD current levels. Thus, the Variable Frequency Drive can serve each just in case of Speed Control of Motor additionally as energy savings.

In addition, this paper will discuss the comparison between Variable Frequency Drives and alternative technologies with respect to industrial standards [1].

5. CHALLENGES OF USING VARIABLE SPEED MOTOR DRIVES

Eric Pearsson et. al. did research on "The challenges of using a variable speed motor drives in appliances applications". This paper presents the reasons why permanent magnet motors (and their necessary drive and control electronics) are used and challenges in doing so in a cost-effective manner. The problems of using conventional AC induction motor in refrigerator & air conditioner applications and washing machine are described with the solution of using variable frequency drive., but in an implementation of VFD some challenges are faced.

One of these is the challenges of sensorless control. The various challenges of sensorless control include estimating position, torque at zero speed and accurate, low-cost phase-current sensing. For this the back EMF can be calculated with stator current and voltage as shown below Flux is calculated through integration. Angle calculated from sine and cosine flux function.



$$v_\alpha = R_S.i_\alpha + L_S.\frac{di_\alpha}{dt} + \frac{d}{dt}(-n.\phi_r.\cos(\theta_r)) \quad (1)$$

$$v_\beta = R_S.i_\beta + L_S.\frac{di_\beta}{dt} + \frac{d}{dt}(-n.\phi_r.\sin(\theta_r)) \quad (2)$$

$$\therefore$$

$$L_s.i_\alpha - n.\phi_r.\cos(\theta_r) = \int(v_\alpha - R_S.i_\alpha)dt \quad (3)$$

$$L_s.i_\beta - n.\phi_r.\sin(\theta_r) = \int(v_\beta - R_S.i_\beta)dt \quad (4)$$

Fig.4 Rotor position estimation [4]

Another one is trapezoidal commutation; motor phase current must rapidly switch from one winding to the next as rotor position advances. But commutation of bus voltage into the motor inductance results in a finite rise-time of current and therefore torque. Trapezoidal commutation has one other significant limitation that it is not possible to operate above "base speed" that is, the speed where the motor back emf equals the bus voltage. For these problems, the Space Vector Modulation is the most suitable solution such that it injects triples current into the applied motor voltage.

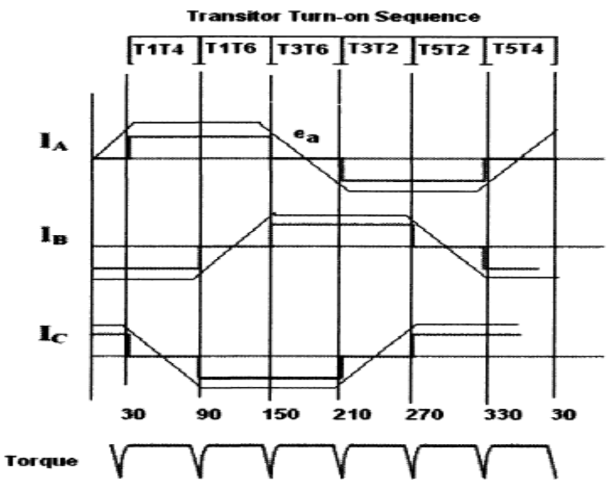


Fig.5 Torque ripple due to trapezoidal commutation [4]

With Field Oriented Control, the three motor phase currents are internally represented as a quadrature pair of Direct and Quadrature signals (d-q) which can be independently controlled. The q-axis current is proportional to torque, and the d-axis current is proportional to magnetization. Normally with PMSM motors, the d-axis current is zero, but it can be driven negative – essentially reducing the effective flux of the permanent magnets.

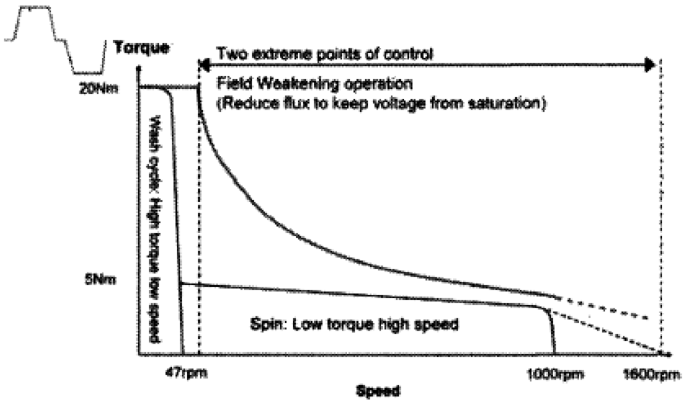


Fig.6 Obtaining high speeds with Field Oriented Control [4]

The final implementation depends on various choices, such as if it is controlled using a microcontroller or digital signal processing (DSP). Insulated Gate Bipolar Transistors are most commonly used.

This paper concludes that by using space vector modulation, field orientation control, estimating rotor position and back EMF and using IGBT controllers it is easy to implement variable frequency drive instead of conventional ACIM motors. [4].

6. CONTROL STRATEGY RESEARCH FOR THE COMBINE AHU

Yuezeng Chen et. al. did research on "Control strategy research for the combine AHU". In this paper, a new control strategy combined with decoupling and the fuzzy theory was studied to improve the comprehensive performance of the combined AHU. Firstly, based on the first principle the dynamics of temperature and humidity were built and transformed into different TFs (transfer function). Then the moisture content was introduced as an intermediate variable and feed-forward compensator was designed, the interaction between temperature control and humidity control was decoupled. Then to adjust the PID parameters adaptively with different operating conditions a fuzzy controller was designed.

In the SIMULINK environment, the Fuzzy PID control model is established, then did simulation for system respectively before and after decoupling, SIMULINK simulation diagram as shown in Fig.7

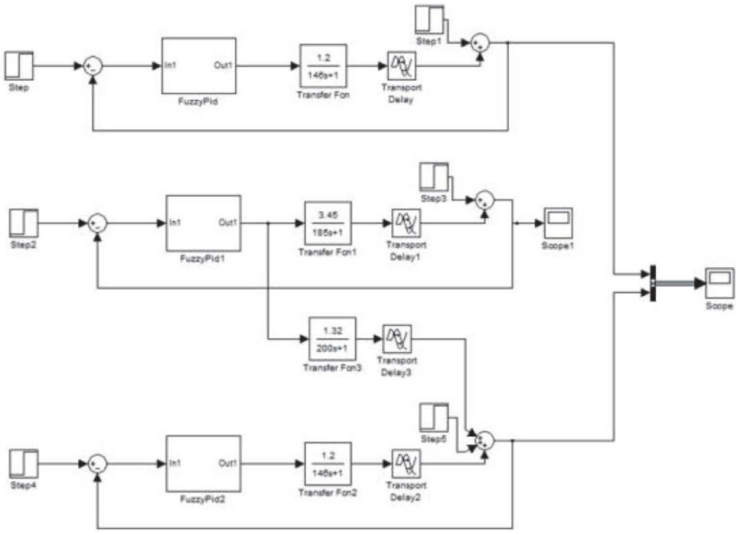


Fig7. The model of Fuzzy PID control [5]

According to the SIMULINK simulation model, the simulation curve of air handling units temperature control is shown in fug. Comparing the two response curves, after decoupling the overshoot of the system response scale down, flat response curve, response time improve.

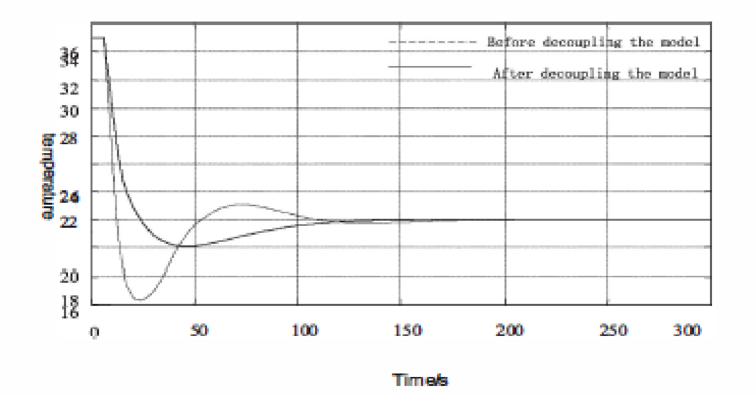


Fig8. The simulation of room temperature [5]

Using SIMULINK to build simulation models of the moisture content of air handling units, because of the heater action has no effect on moisture content, so the moisture content before and after the system decoupling is the same, air handling unit's moisture content control simulation curve is shown in Fig.9

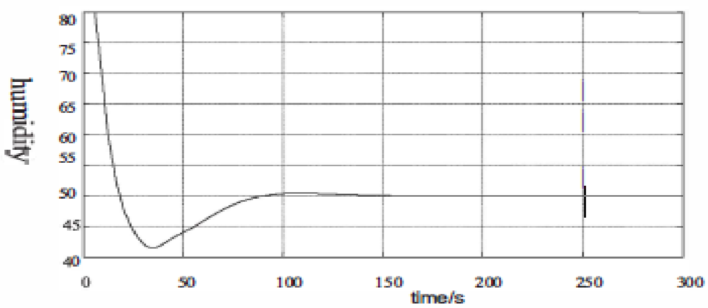


Fig.9 The simulation of the moisture content of room [5]

The results of a case study show that the proposed method is quite effective to the combined AHU, the overshoot and transient time is obviously smaller than the conventional control method [5]

7. PERFORMANCE OF VARIABLE SPEED INVERTOR/MOTOR DRIVE

S. A. Tassou et. al. did research on "Performance of variable speed invertor/motor drive for refrigeration application". In this paper present, the result of an experimental investigation into the application of invertor-based variable speed drives to positive displacement rotary vane refrigeration compressors. The investigation considers the effects of the invertor on a number of operating parameters such as harmonic currents and voltages on both the supply side and motor side, power consumption and power factors, Starting current and overall system efficiency

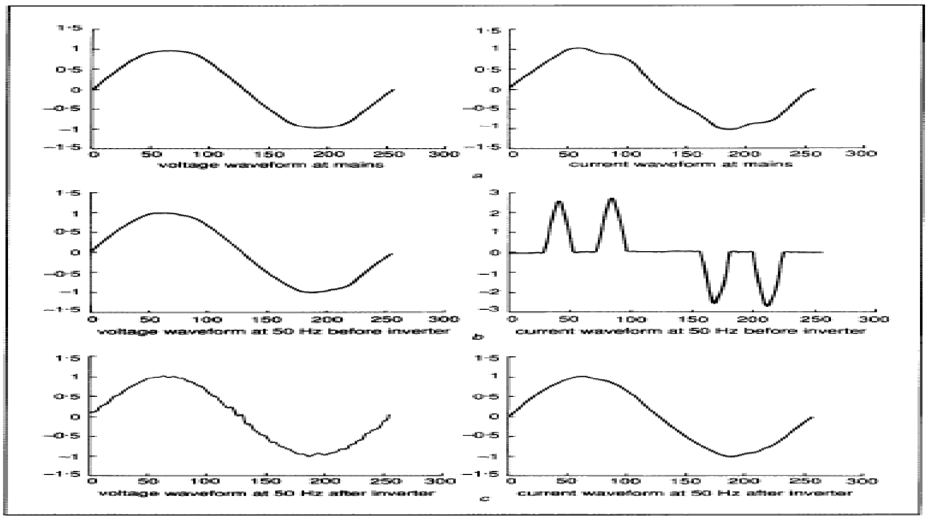


Fig.10 Voltage and current waveform [6]

The results indicate that the use of off-the-shelf invertors for variable speed control of refrigeration compressors can inject harmonic to the supply system which exceeds the maximum limits imposed by BS5406. The invertor may also cause a reduction in the power factor and in the overall efficiency of the drive. Variable speed operation of a rotary vane compressor may not offer efficiency advantages over fixed speed operation but can provide other benefits such as better temperature control and faster response to sudden changes in load [6].

8.REDUCTION OF ENERGY CONSUMPTION THROUGH PARAMETER IDENTIFICATION

Tomas Kostal et. al. did research on "Reducing electrical energy consumption of AHU fans through parameter identification of the drive". This paper deals with a possible solution of lowering energy consumption of induction machine powered fans in air handling units of HVAC systems. First, it presents the influence of a change of parameters of the induction machine to a field-oriented control that is a common algorithm of control of induction machines. It further specifies the area where power consumption optimization could be achieved and proposes usage of a method that could respect the change of parameters and thus improve the control.

Nowadays, almost all new systems can control the airflow of fans by adjusting the speed of their electric drive Two methods are mainly used for speed adjustment of VFD are scalar (V/f) control it does not require any mathematical model of the machine and Field oriented control which uses a mathematical model of the machine Method called Robust on-line tuning of parameters was selected for simulation test because its comparatively simple implementation full fills conditions.

Simulation has been carried out for different on-line parameters such as instantaneous

stator voltage and current, rotor angular speed, torque component, flux component, stator resistance, leakage inductance, magnetizing inductance and rotor resistance and from simulation reactive power of the machine is calculated. Which helps to determine that machine is loaded or not and according to that the rotor resistance is a change which controls the fan speed [7].

9. REDUCTION OF ENERGY CONSUMPTION THROUGH INTEGRATION OF DRIVE

Karl Braun et. al. did research on "Reducing energy consumption of AHU fans through the integration of variable frequency drive". In this paper Variable frequency drives (VFD) enables control of the speed of three-phase motors which allows the motor to be operated with variable current inputs. This technology can be used in Heating, Ventilation and Air Conditioning (HVAC) systems to lower fan operating speeds, reducing energy consumption. The client has expressed a necessity for a more effective means of control for the operation of their two air handling units which regulate airflow throughout their office building located on a brewing facility campus. Currently, the provision of fans for each air handlers (AHUs) operate at full capacity, regardless of occupancy of the building. The implementation of Variable Frequency Drives (VFDs) on these supply fans was explored due to the client's would like to lower operating expenses for the HVAC system serving the building studied by automating the Air Handler control.

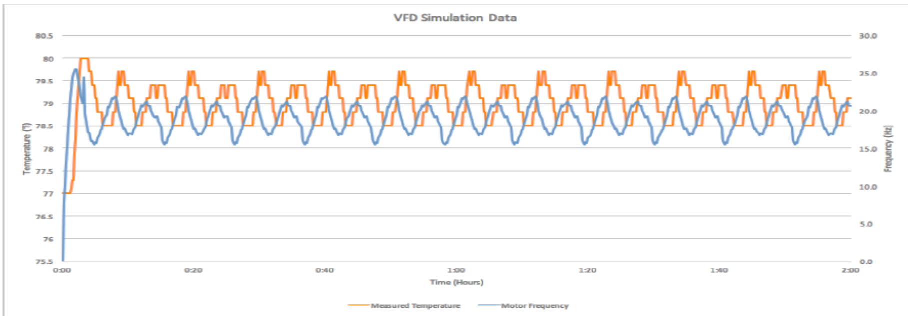


Fig. 11 Baseline and VFD controlled experimental data over 2 hours [8]

Using industry simulation and estimating software Danfoss VLT Energy Box simulator a VFD schedule was developed to determine the capacity for operational cost savings for these two rooftop units, based on occupancy of the building. During weekends and non-business hours during the week, the power to the supply fans was modelled at lower percentages of the full operational capacity.

Based on the specifications, the resulting values for the annual cost savings is estimated to be $7,650.00 for the supply fan for each unit. The combined savings by implementing the use of VFD drive systems on both units will yield an estimated $15,300.00 annually. The implementation of VFDs and installation costs is estimated to be $5750.00. The results of this analysis show that the implementation of VFDs on these two air handling units can reduce operational HVAC costs by 18% [8].

10.SPEED CONTROL OF SINGLE-PHASE INDUCTION MOTOR

Aung Zaw Latt et. al. did research on "Variable speed drive of single-phase induction motor using frequency control method". In this paper, variable speed drive of induction motor using a frequency control method is used to develop the solid-state control system to be reliable and economically feasible to use with fractional horsepower motors. The suggested variable speed drive includes a power conversion section (AC to DC and DC to AC), used the switching element of IRF 840 N-channel MOSFET.

To provide the alternating current to the motor four IRF 840 MOSFETs are used as H-bridge inverter. In this drive, to drive the H-bridge inverter, the C124 transistors and MJE 13002 transistors are used as the driver circuit. Two power supplies are used in this drive. For the frequency control circuit and a driver circuit, 12 V power supply is used. For H-bridge inverter 300 V power supply is used. In this drive, for frequency control, pulse width modulation SG3525A IC is used. For changing the speed of induction motor, the frequency range of the constructed variable drive circuit is 16 Hz to 56 Hz at a constant voltage.

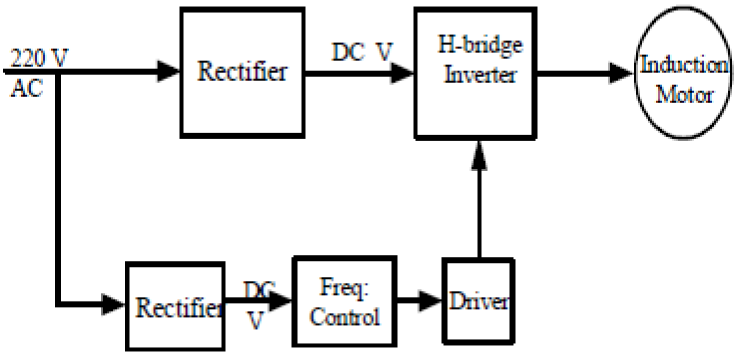


Fig. 12 Block Diagram for the Speed Control of Single-phase Induction Motor Using Inverter [9]

In this research paper, drive schemes of single-phase induction motor, principal operations of components used in constructed variable speed drive, and design calculation to construct this drive are included. Moreover, the experimental tests of this drive when driving a fractional horsepower single-phase induction motor is described

Design considerations for speed control system can be divided into four parts, rectifier, PWM control circuit, driver circuit and H-bridge inverter. The main task in this drive is to make a compact open-loop sinusoidal PWM inverter to control the speed of a single-phase induction motor. This compact inverter had its hardware reduced to a minimum through the use of H-bridge inverter which is composed of four IRF 840.

Table 3 Calculated and test results of variable speed drive [9]

Regula -tor (kΩ)	Calculated Results		Test Results	
	Freq (Hz)	*Speed (rpm)*	*Freq (Hz)*	*Speed (rpm)*
150	17	510	16	480
100	24	720	23	690
80	30	880	28	840
60	35	1050	33	990
40	46	1380	42	1260
20	66	1980	56	1680

The experimental results show that the single-phase induction motor can be successfully driven from a variable frequency and the speed of the motor can be easily adjusted using the proposed variable speed drive used with frequency control method. [9]

11. DETECTING THE CORRECT ROTATIONAL DIRECTION OF A CENTRIFUGAL DEVICE

Jussi Tamminen et. al. did research on "Detecting correct rotational direction of a centrifugal device with a variable frequency drive". This paper presents a sensorless method that can detect the correct rotational direction of a centrifugal device. The method is verified by laboratory tests for a pump and blower system. The direction of flow in a centrifugal device is independent of the rotational direction of the impeller. However, the price of an incorrect rotational direction is significantly lower efficiency and a dramatically reduced service life. The correct rotational direction is traditionally found by visual inspection, but the centrifugal device can be in such a location that the visual inspection is impossible. Therefore, methods that can detect the correct rotational direction, preferably without additional sensors, are needed.

The low-frequency shaft power fluctuation increases significantly when the device is rotated in the reverse direction the frequency component in the shaft power that corresponds to the electrical supply frequency increases significantly when the device is rotating in the reverse direction. The low-frequency fluctuation can be clearly seen in the time-domain behaviour of the rotational speed estimate as shown in Fig.13.

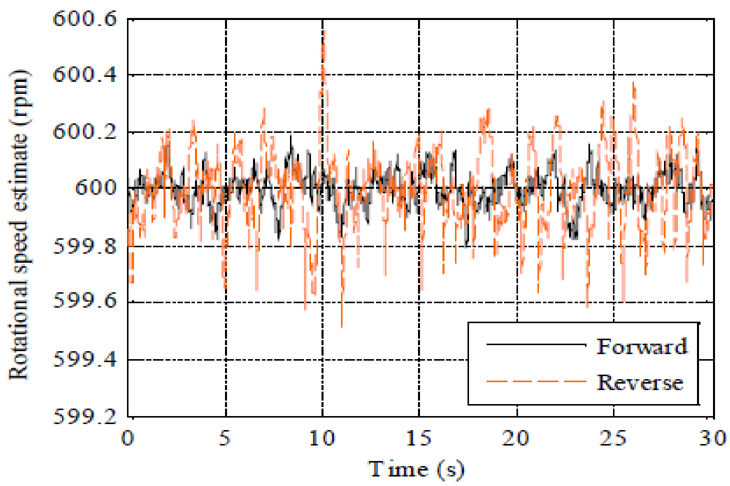


Fig. 13 Time domain signal of the rotational speed estimate with forward and reverse directions [10]

In this paper, a novel method that can be used in the detection of the correct rotational direction of a centrifugal device is presented. The VSD estimates of the motor rotational speed and torque are used in the detection thereby making the presented method sensorless. In the method, the centrifugal device is rotated in both directions, and these directions are compared with each other according to the following features: low-frequency estimate fluctuation and supply frequency component. A higher level in these features indicates a reverse rotational direction [10].

12.CONCLUSION:

The conclusion that can be drawn from analysis of the above papers can be summarized as follow:

1. Total air volume control is one of the energy efficient systems.
2. By using SVM, field orientation control, estimating rotor position, back emf and using IGBT controllers also some on-line parameters it is easy to control the VFD.
3. Also, decouple and fuzzy logic control, solid state controls helps to lower the energy consumption of AHU.
4. It is efficient to vary the frequency of VFD in between 45 to 70 Hz for energy saving, also the blower housing and the directions of rotation plays an important role in the consumption of energy.

13. REFERENCES:

[1] Tamal Aditya, “Research to study variable frequency drive and its energy saving”, International Journal of Science and Research (IJSR), June 2013, pp. 253-256.

[2] Yuying Sun, Zhoglei Zheng, Xun Hou, Peizhe Yian, "AHU control strategies in the VAV system", Fourth International Conference on Innovative Computing, Information and Control (ICICIC), Dec. 2009, pp.119-123

[3] Garron K Morris, Bruce W Weiss, "Driving energy efficiency with design optimization of a centrifugal fan housing system for variable frequency drive", Inter-Society Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, June 2012, pp. 1312-1319.

[4] Eric Pearsson, Athula Kulatunga, Raji Sundararajan, “The challenges of using a variable speed motor drives in appliances applications", Electrical Insulation Conference and Electrical Manufacturing Expo, Oct. 2007, pp. 453-458.

[5] Yuezeng Chen, Xiaolong Yu, Shuang Hu, Qiang Ding, "Control strategy research for the combine AHU", Chinese Automation Congress (CAC), Nov. 2015, pp.2130-2134.

[6] S. A. Tassou, T. Q. Qureshi, "Performance of variable speed invertor/motor drive for refrigeration application", Computing and Control Engineering Journal, Aug. 1994, pp. 193-199.

[7] Tomas Kostal, "Reducing electrical energy consumption of AHU fans through parameter identification of the drive", 3rd International Conference on Intelligent Green Building and Smart Grid, April 2018, pp. 978-981.

[8] Karl Braun, Evan Eaves, Christopher Giambri, Dylan Champman, Hunter Heavner, "Reducing energy consumption of AHU fans through the integration of variable frequency drive", System and Information Engineering Design Symposium, April 2016, pp. 61-65.

[9] Aung Zaw Latt, NI Ni Win, "Variable speed drive of single phase induction motor using frequency control method", International Conference on Education Technology and Computer, April 2009, pp. 30-34.

[10] Jussi Tamminen, Tero Ahonen, Jero Ahola, Lauri Niinimaki, Jukka Tolvanen, "Detecting correct rotational direction of a centrifugal device with a variable frequency drive", European Conference on Power Electronics and Applications, Sept. 2013, pp. 331-340.