



**Improvement of Based Sector and Dynamic Response  
of Direct Torque Control Using Supercapacitor**

by

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## LIST OF ABBREVIATIONS

VFD	Variable Frequency Drive
DTC	Direct Torque Control
IM	Induction Motor
FOC	Field Oriented Control
V	Voltage
F	Frequency
EV	Electric Vehicle
SC	Supercapacitor
PSO	Partial Swarm Optimization
DC	Direct Current
AC	Alternating Current
SPIM	Single-Phase Induction Motor
THD	Total Harmonic Distortion

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## LIST OF SYMBOLS

$T_e$	Torque Equivalent
$\omega_e$	Speed equivalent
$\theta_e$	Phase equivalent
$P$	Pole Pair Number
$V$	Voltage
$f$	Frequency
$\omega_r$	Synchronous Speed
$s$	Slip
$n$	Rotor Turn Ratio

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# Penambahbaikan Berasaskan Sektor dan Tindak Balas Dinamik Kawalan Kilas Langsung Menggunakan Superkapasitor

## ABSTRAK

Permintaan tenaga di seluruh dunia meningkat pada kadar yang belum pernah terjadi sebelumnya. Ini telah menunjukkan kesannya terhadap penipisan sumber tenaga dan masalah persekitaran (pemanasan global dan kelemahan lapisan ozon). Pola kekurangan tenaga yang semakin meningkat ini, tentu saja, akan meningkat pada masa akan datang. Merujuk kepada literatur, penjimatan tenaga yang ketara dapat dicapai dengan mengawal kelajuan sistem motor elektrik menggunakan pemacu frekuensi berubah (VFD). Kawalan kilas langsung (DTC) adalah salah satu teknik kawalan kilas yang paling berkesan untuk motor aruhan. Pada masa kini, teknologi superkapasitor (SC) secara meluas dianggap sebagai salah satu teknologi yang paling menjanjikan dan cekap tenaga untuk sistem penyimpanan tenaga generasi akan datang berbanding dengan bateri Arus Terus (AT). Mesin berputar menghasilkan getaran yang membawa kepada dinamik pemutar. Oleh kerana itu, peningkatan sektor berasaskan DTC dapat mengurangkan peningkatan dinamik rotor dibandingkan dengan DTC lazim. Tesis ini menunjukkan peningkatan sektor berasaskan untuk kaedah enam sektor dan kaedah dua belas sektor motor induksi dalam kerangka simulasi MATLAB Simulink dengan menggunakan penyimpanan tenaga yang berbeza (superkapasitor dan bateri AT). Hasil sistem yang dirancang dalam MATLAB Simulink telah dibandingkan dan dianalisis dari segi kelajuan pemutar, elektromagnet kilas dan arus stator d-q. Dalam aspek kelajuan pemutar, penggunaan kaedah dua belas sektor 0.04 saat peralihan kelajuan untuk mencapai tindak balas keadaan stabil berbanding dengan kaedah enam sektor yang memerlukan 0.06 saat untuk mencapai keadaan stabil apabila gangguan beban diperkenalkan untuk bateri AT dan superkapasitor. Elektromagnet kilas yang menggunakan kaedah dua belas sektor memberikan lebih lancar mengikuti kilas beban membandingkan kaedah enam sektor untuk bateri AT dan superkapasitor. Elektromagnet kilas dalam kaedah dua belas sektor menghasilkan kilas runcing sekitar 15.5N sementara dalam kaedah enam sektor menghasilkan 18N ketika gangguan beban diperkenalkan. Penggunaan superkapasitor lebih baik ketika di permulaan motor membandingkan bateri AT sama ada dalam elektromagnet kilas dan arus stator. Dalam aspek elektromagnet kilas, penggunaan superkapasitor menghasilkan 15N sementara penggunaan bateri menghasilkan sekitar 50N untuk kaedah enam sektor dan kaedah dua belas sektor. Dalam aspek arus stator, penggunaan bateri menghasilkan 40A sementara penggunaan superkapasitor menghasilkan 20A untuk kedua-dua kaedah tersebut. Pelaksanaan kaedah dua belas sektor prestasi dinamik yang lebih baik untuk mencapai bentuk gelombang yang stabil berbanding dengan kaedah enam sektor.

## Improvement of Based Sector and Dynamic Response of Direct Torque Control Using Supercapacitor

### ABSTRACT

Energy demand worldwide is rising at an unprecedented pace. This has already shown its impact on the depletion of energy sources and environmental issues (global warming and the weakening of the ozone layer). This growing pattern of energy insufficiency will, of course, intensify in the future. Referring to the literature, significant energy savings can be achieved by controlling the speed of the electric motor system using variable frequency drives (VFDs). Direct torque control (DTC) is one of the most effective torque control techniques for induction motors. Nowadays, supercapacitor (SC) technology is widely regarded as one of the most promising and energy-efficient technologies for next generation energy storage systems as compared to DC battery. Rotating machinery produce vibration that leads to rotor dynamic. Due to that, the improvement of based sector of DTC can reduce the increasing of rotor dynamic compared to conventional DTC. This thesis is demonstrated the improvement of based sector for six sector and twelve sector method of induction motor in MATLAB/Simulink simulation framework by using different energy storage (supercapacitor and DC battery). The result of the system that been design in MATLAB Simulink has been compared and analysed in term of rotor speed, electromagnetic torque and d-q stator current. In aspect of rotor speed, the uses of twelve sector method 0.04 second speed transition to achieve steady state response as compared to six sector method which need 0.06 second to achieve steady state when load disturbance is introduced for DC battery and supercapacitor. The electromagnetic torque that uses twelve sector method give more smoothly following the load torque compare six sector method for DC battery and supercapacitor. The electromagnetic torque in twelve sector method produces spiky torque about 15.5N while in six sector method produce 18N when load disturbance is introduced. The use of supercapacitor is better when at motor start-up compared DC battery whether in electromagnetic torque and stator current. In electromagnetic torque aspect, the use of supercapacitor produces 15N while the uses of battery produce about 50N for six sector and twelve sector method. In stator current aspect, the uses of battery produce 40A while the uses of supercapacitor produce 20A for both methods. The implementation of twelve sector method better dynamic performance to achieve steady waveform as compared to six sector method.

## CHAPTER 1 : INTRODUCTION

### 1.1 Research Background

Initially, the California Air Resources Board (CARB) urged the use of electric vehicles (EVs) as a direct indicator to reduce emissions from automotive users [1]. The preliminary findings indicated that if battery manufacturers worked closely with the improved battery capacity and energy density, as well as cycle life, with the help of the vehicle electrical system engineering team, the obstacles to widespread adoption of EVs could be overcome and fuel efficiency targets met [2],[3]. Electroactive materials, current collector conductivity and chemical consistency, electrode anatomy-related electrolytes, redox behaviour of additives in electrodes or electrolytes, and overloading also contribute to the battery's performance failure over time. While significant progress has been made in improving battery capacity over the past decades, the key issue is peak consumption. In addition, battery damage happens when the battery in small electronic devices like phones and notebooks capacity is consumed randomly. This is a constant variable such as driving style, lane, and other factors that create rapid fluctuations in power usage in electric vehicles. After a battery has been discharged in a regular manner, the electrochemical reaction that results would also be consistent. However, because an EV requires more power during acceleration, the battery pack cannot be discharged quickly enough to meet this requirement. The same can be said for storing high current produced by EV braking in the batteries. The electrolytes will be damaged by such fluctuating flows of a strong electric current into and out of the battery.

If this acceleration/braking often occurs (for example, in city driving), the battery life can be reduced.

In electric vehicles, various kinds of batteries have been used [4]–[7]. However, the most promising is the Lithium-ion (Li-ion) battery, which is the most prevalent form of energy storage in portable electronic devices like phones and laptops. Scaling up Li-ion batteries for EVs is more complex than scaling up Li-ion batteries for small electronic devices due to the unique course of energy consumption in EVs. As a result, new Li-ion batteries for electric vehicle applications may be produced. In modern Li-ion batteries, it is important to reduce cell voltage with different electrode materials that may be used for other applications to boost other factors such as rate strength or cyclability, and different electrode materials may be used to boost other factors such as rate strength or cyclability [8],[9]. Many Li-ion batteries used in EVs, for example, are built for high-rate efficiency and outstanding EV output cyclability utilising  $\text{LiFePO}_4$ , which, though not the most common cathode material in small Li-ion batteries, has substantial promise for high-rate efficiency and outstanding EV output cyclability, as discussed below [10]–[13].

Supercapacitors (SCs) are electrochemical energy storage technologies that differ in that they have a high-rate capacity for quick charging and discharging. They cannot be used as an EV's power source because they have a lower energy density than batteries. They are, however, decent choices for reducing high demand peaks at brief periods of time when battery capacity is insufficient. The function of the coupled SC, in this case, is similar to that of supplying electricity instantly on traditional capacitors in electronic devices. SCs have a similar electrical reaction to conventional capacitors, with the exception that the true capacitance is much higher, as the prefix

suggests. In a scientific sense, the word “supercapacitor” was first applied to electrochemical devices with capacitive or pseudo-capacitive actions, but it was later applied commercially to the first generation of double-layer capacitors. The electrochemical redox mechanism, rather than double layer charging, determines the performance of so-called pseudocapacitors. While this results in a much higher specific power, the cycle of supercapacitor is drastically reduced. SCs have been emphasized in many published papers as being able to operate more efficiently over 30 000 h compare any other energy storage (ESS) device [14]–[17].

High instant power and high-power density are the most important characteristics of an EV drive device. Furthermore, high torque at the low start and climb rates, as well as high power at high cruise speeds, provide a full range of speeds with constant torque and constant power regions. Furthermore, fast torque response with high efficiency over a large speed and torque range was also needed for electric vehicles, as was high efficiency for regenerative braking. Last but not least, for an EV drive system, good reliability and robustness for different vehicle operating conditions, as well as a competitive cost, have been evaluated [2],[18],[19]. Thus, the most critical considerations in EVs are the specification of an appropriate drive and control system; additionally, efficient energy conservation is the other key aspect of an EV [20],[21].

Because of its durability, low cost, modern technologies, and maintenance-free operation, the induction motor (IM) is an excellent option for electric vehicle applications. From the standpoint of the control engine, the control system is the key to improving motor capacity, expanding battery life, and thereby increasing driving distance [22],[23]. Between various motor drives, sensorless control as a variable frequency drive is now a mature technology. The sensorless

control is suitable for high-reliability, high-performance, and energy-saving applications such as electric vehicles [24]. Field oriented control (FOC) and direct torque control are the two most popular sensorless control methods used by IM (DTC). Unlike FOC, DTC does not need coordinate transition, PWM signal generators, current controllers, or a location encoder with delays and mechanical transduction. In this thesis, the direct torque control used as control technique for the induction motor. The main storage for the system that been compared which are DC battery and supercapacitor. Based on the system, the improvement-based sector for DTC can increase the efficiency of the induction motor.

## 1.2 Problem Statement

The fundamental technical idea behind VFD is controlling motor speed. If a motor speed can be regulated to suit the process demand, system efficiency can be enhanced. For example, to save the energy used in a household air conditioning unit, one can either increase the temperature or reduce the fan speed. However, the energy saved is marginal because the induction motor is operating at standard acceleration. The major disadvantage of (IM) is the coupling between their stator and rotor magnitudes. So, in order to improve the dynamic behaviour of the asynchronous machine, DTC technique been introduced as most effective torque control technique for induction motor. The uses of DC battery not suitable for induction motor to cater high torque, high current at motor start-up as main storage for DTC with induction motor. Besides that, the conventional DTC algorithm is the use of six non-zero voltage vectors by the voltage source converter, since the desired torque is satisfied for only few switching points and the most voltage vectors introduce a torque which is either greater or less than the desired torque. Rotating machinery that uses

induction motor produce vibrations that leads to rotor dynamic analysis which are speed, torque and current. Based on the consequences, the improvement of based sector of DTC can leads to increase the efficiency of induction motor operation.

### **1.3 Research Objective**

The objectives of this research are:

1. To develop direct torque control for induction motor with a battery and a supercapacitor.
2. To compare six sector and twelve sector method for direct torque control system with induction motor.
3. To analyse the dynamic response of direct torque control using supercapacitor and DC battery.

### **1.4 Research Question**

1. What problem with the energy storage of the induction motor using the battery and supercapacitor?
2. What improvement of methodology of direct torque control needed?
3. How the improvement of the direct torque control helps the induction motor to give better performance?

## 1.5 Scope of the Study

The scope of this research is:

1. Design variable frequency drive on an induction motor with DC battery and supercapacitor for input supply 400V.
2. Design the control for variable frequency drive to control induction motor using direct torque control technique with six sector method and twelve sector method based on the specification of the 3-phase induction motor used is 2.2kW, 1485rpm, four poles with the frequency of 50hz and rated voltage 400V.
3. Analysing the result of the system that been design in MATLAB Simulink in term of rotor speed, electromagnetic torque and d-q stator current for 0.5 second.

## CHAPTER 2 : LITERATURE REVIEW

### 2.1 Introduction

This chapter will cover the study and review that needed to know in order to develop this project complete and functioning correctly. Many findings from this field are mainly generated from journals for others to take advantage of and improve as upcoming studies. Firstly, study and review of variable frequency drive (VFD), type of VFD, working principle of VFD and highlighted the advantages and disadvantages of VFD. Besides that, review on the methodology use in variable frequency drive that are six sector method and twelve sector method. Also, study of application and previous work of the variable frequency drive. Lastly, review on energy storage which are DC battery and supercapacitor.

### 2.2 Variable Frequency Drive (VFD)

The semiconductor revolution of power electronic devices was introduced in the early 1960s to aid in the design of a variety of power electronic converters, including inverters, rectifiers, and DC-DC converters[1]. The induction motor drive was operated using a switching technique. As a result, several bodies of study have planned and improved VFD approaches for control purposes. A variable-frequency drive is described as a sort of adjustable-speed drive used in electromechanical drive systems to regulate AC motor velocity and torque by varying motor input and voltage frequencies[2]. Variable speed drive technology provides a cost-effective technique to match driver speed to load requirements and is an opportunity to decrease operating costs and

enhance general productivity. The use of this VFD is now prevalent in our daily life. VFDs are produced accessible for heavy industries using AC and DC motors in electrical equipment as small table fans and room air conditioning units. Toyota developers have integrated this VFD technology for their green technology cars, such as Toyota Hybrid Prius. Basically, the VFD requires to understanding three primary section that are rectifier unit, DC bus unit and inverter unit as shown in Figure 2.1.

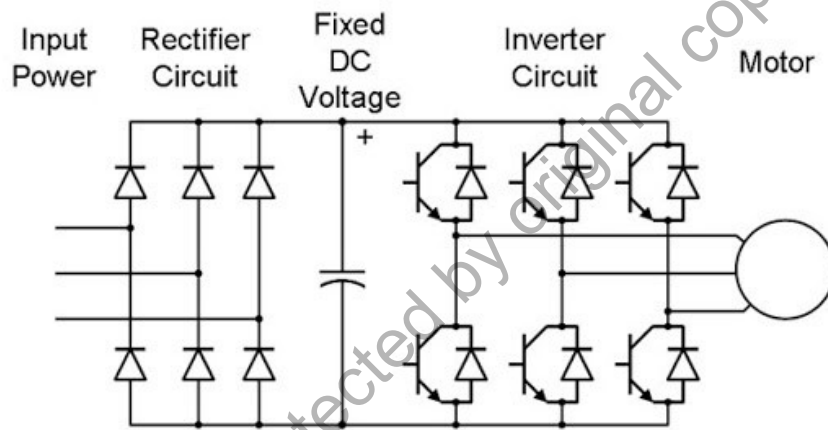


Figure 2.1 VFD Circuit Diagram[3]

Without getting into the technical intricacies of how a VFD works, it's worth noting some of the downsides of this extremely efficient gadget. For starters, a VFD producer must address the heat problem initially[3]. Manufacturers of VFDs are unable to create an optimum collection of components to counterbalance heat in the drive. In most circumstances, VFDs have an efficiency rating of 95 to 98 percent[4]. As seen in Figure 2.2, VFDs may be classed into two types of control techniques: scalar control and vector control.

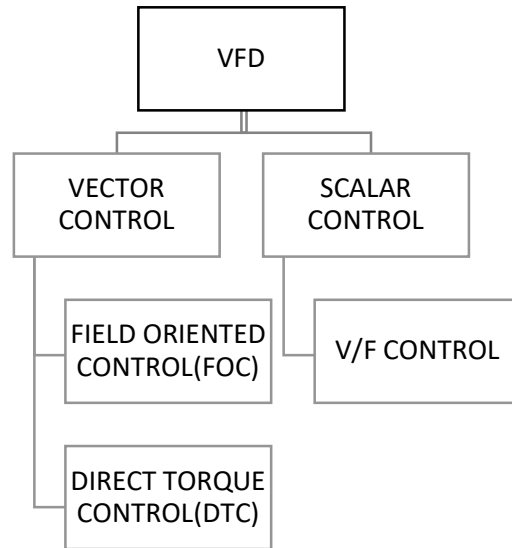


Figure 2.2 Type of variable frequency drive technique[5]

### 2.3 Scalar Control

One of the control techniques used in VFDs for induction motors is scalar control. Scalar control legislation, unlike vector control, is drawn from the IM steady-state model[6]. It only requires a difference in magnitude to modify the speed or torque of a vehicle, use control variables in single-phase induction motors while disregarding system coupling. But scalar control has a better control technique for three-phase induction motors[7], [8]. These control systems cannot be used to single-phase induction motors in the same manner that they can to the differing torque-speed action of single-phase induction motors under variable frequency supply; three-phase induction motors are used. The open-loop and closed-loop control of the induction motor speed system is needed for this control. Some applications do not require open-loop induction motor system speed system control, such as air conditioning, ventilation, fan and blower application[9].

### 2.3.1 Voltage/Frequency Technique

Voltage/Frequency (V/F) control is built on the IM speed's open-loop and closed-loop control systems. This control method, known as scalar control, was first used in 1960 for IM control[9],[10]. In the open loop control system, the speed response accuracy is not required for the system, such as ventilation, air conditioning, fan and blower application. In a closed-loop control system, the variable voltage and frequency of an IM are always used to control the speed and torque of IM drives [11]. On IM drives, the V/F control technique is used to optimize performance and dynamic response. This approach has a number of benefits, including a straightforward shape, low cost, easy construction, low steady-state error, and low initial current requirement. Aside from that, changing the supply frequency will control the acceleration and deceleration of the IM motor. V/F regulation is one of the best options for variable speed and torque applications because it controls the magnitude of the IMs' supply voltage. The V/F controls work on the concept of maintaining a constant scalar voltage and frequency ratio in order to ensure overall air gap magnetic flux.

### 2.3.2 Control System of V/F Technique

This technique is often used in applications where accurate single-phase induction motor control is just not required. Examine Equation (2.1) and Equation (2.2) generated from the reduced form of the single-phase induction motor equivalent steady-state circuit to see how this method works.