DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

COORDINATED CONTROL OF A BACK-TO-BACK HVDC LINK

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ABSTRACT

THIS THESIS WILL PRESENT THE MATHEMATICAL MODEL, CONTROLLER DESIGN, SIMULATION, ANALYSIS OF A COMPLETE BACK-TO-BACK VSC HVDC SYSTEM. THERE WILL BE TWO STATIONS O VOLTAGE SOURCE CONVERTER (VSC) LOCATED BACK-TO-BACK. ONE STATION SHALL ACT AS A RE AND ANOTHER ONE WILL BE THE INVERTER. THIS WILL ALLOW POWER TRANSFER FROM ONE STATIO (RECTIFIER) TO OTHER (INVERTER) THROUGH A DC LINK. A BACK-TO-BACK VSC HVDC HAS TH ADVANTAGES COMPARE TO THE AC TRANSMISSION BECAUSE IT CAN ALLOW POWER TRANSFER WI HAVING TO SYNCHRONIZE BOTH OF THE STATION OR NETWORKS. IN ORDER TO COMPLETE A BACK-T VSC HVDC SYSTEM, IT WILL REQUIRE A D-Q CURRENT CONTROLLER, DC VOLTAGE CONTROLLER, ACTIVE/REACTIVE POWER CONTROLLER AND DC POWER (DC CURRENT CONTROLLER). A SIMULATION A ANALYSIS SHALL BE EXECUTED FOR EACH OF THE CONTROLLER AND RESPONSE OF VOLTAGE AND CURRE A COMPLETE SYSTEM. THE SIMULATION RESULT WILL SHOW THE DYNAMIC CONTROL OF THE RECTIFIE INVERTER IS ACHIEVED WITH FAST RESPONSE.

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SYMBOL AND ABBREVIATION

HVDC	-	HIGH V0LTAGE DIRECT CURRENT
UHVDC	-	ULTRA-HIGH V0LTAGE DIRECT CURRENT
AC	-	ALTERNATING CURRENT
DC	-	DIRECT CURRENT
IGBT	-	INSULATED-GATE BIP0LAR TRANSIST0R
PLL	-	PHASE L0CKED L00P
LCC	-	LINE-C0MMUTATED CURRENT-S0URCE C0NVERTER
SCC	-	SELF-C0MMUTATED V0LTAGE-S0URCE C0NVERTER
PWM	-	PULSE WIDTH M0DULATI0N
EMI	-	ELECTR0MAGNETIC INTERFERENCE
P	-	ACTIVE P0WER
Q	-	REACTIVE P0WER
ABC	-	THREE PHASE
R	-	RESISTANCE
L	-	INDUCTANCE
C	-	CAPACITANCE
P_{REF}	-	ACTIVE P0WER REFERENCE VALUE
Q_{REF}	-	REACTIVE P0WER REFERENCE VALUE
I_{DREF}	-	D-AXIS CURRENT REFERENCE VALUE
I_{QREF}	-	Q-AXIS CURRENT REFERENCE VALUE
α	-	ALPHA
β	-	BETA
V_d	-	D-AXIS V0LTAGE
V_q	-	Q-AXIS V0LTAGE
V_{td}	-	D-AXIS RECTIFIER TERMINAL V0LTAGE
V_{tq}	-	Q-AXIS RECTIFIER TERMINAL V0LTAGE

I_d	-	D-AXIS CURRENT
I_q	-	Q-AXIS CURRENT
$\hat{\theta}$	-	V0LTAGE ANGLE
f_s	-	SWITCHING FREQUENCY
f	-	FREQUENCY
T_s	-	SWITCHING PERI0D
V_{dc}	-	DIRECT CURRENT V0LTAGE
V_s	-	SUPPLY V0LTAGE
V_{sabc}	-	THREE PHASE SUPPLY V0LTAGE
V_a	-	PHASE A V0LTAGE
V_b	-	PHASE B V0LTAGE
V_c	-	PHASE C V0LTAGE
I_{sabc}	-	THREE PHASE SUPPLY CURRENT
V_{tabc}	-	RECTIFIER TERMINAL V0LTAGE
$\hat{V}_{ac}$	-	PEAK ALTERNATING-CURRENT V0LTAGE VALUE
$\hat{I}_{ac}$	-	PEAK ALTERNATING-CURRENT CURRENT VALUE
ξ	-	DAMPING FACT0R
ω_n	-	NATURAL FREQUENCY
K_p	-	PR0P0RTI0NAL GAIN
K_i	-	INTEGRAL GAIN
τ	-	TIME C0NSTANT
G(S)	-	TRANSFER FUNCTI0N

CHAPTER 1

INTRODUCTION

1.1 RESEARCH BACKGROUND

THE HIGH VOLTAGE DIRECT CURRENT (HVDC) SYSTEM IS FIRST TIME COMMISSION
GOTLAND IN 1954. SINCE THEN, THE HVDC TRANSMISSION SYSTEM BECOMES MORE IMPOR
TECHNOLOGY ESPECIALLY FOR LONG DISTANCE TRANSMISSION AND IN THE INTERCONNEC
POWER SYSTEM THAT HAS DIFFERENT FREQUENCY. THE HVDC LINK IS ABLE TO OVERCOME S
THE LIMITATIONS OF AC SYSTEM SUCH AS NO LIMIT FOR THE TRANSMISSION CABLE LENGT
FROM IMPEDANCE, PHASE ANGLE, FREQUENCY OR VOLTAGE FLUCTUATIONS, LOWER SHORT C
AND IMPROVE THE AC SYSTEM'S CONTROLLABILITY AND STABILITY.

THERE ARE FEW TOPOLOGY OR TYPES OF HVDC SCHEMES AND ONE OF IT IS THE BA
BACK CONVERTER. FOR THIS TYPE OF CONVERTER, THE RECTIFIER AND INVERTER ARE LOCAT
AREA AND USUALLY IN THE SAME BUILDING. THIS WILL HELP TO LIMITS THE CONVERSIO
INCREASE THE EFFICIENCY. THE MAIN APPLICATIONS OF THIS TYPE OF CONVERTER ARE TO IN
SYSTEM WITH DIFFERENT FREQUENCIES (E.G: 50 AND 60HZ). IN AC NETWORK SYSTEM, IT IS
POSSIBLE TO CONNECT THE TWO SYSTEM WITH DIFFERENT FREQUENCY. THEREFORE A VOLT
CONVERTER (VSC) IS USED IN THE HVDC SYSTEM TO CONTROL THE POWER FLOW BETWEEN T
NETWORKS THROUGH THE DC LINK. THE VSC IS CONSIDERED A NEW TECHNOLOGY WHICH I
IGBT AS IT SEMICONDUCTOR SWITCHING COMPONENT, REPLACING THE THYRISTOR WHICH
THE 'CLASSIC' HVDC. THE IGBT HAS THE CAPABILITY TO TURN-ON AND TURN-OFF WHILE
ONLY HAS THE CAPABILITY TO TURN-ON. WITH THE SWITCHING METHOD BECOME MORE CO

CONTROLLER TO GENERATE SIGNAL MODULATION ALSO AFFECTED. A GOOD DESIGN OF C PROVIDE A COORDINATED CONTROL OF HVDC LINK WHICH CAN HELP TO ENSURES F INTERCONNECTION AMONG THE CONTROLLABLE DEVICES.

THIS PROJECT WILL FOCUS ON THE CONTROL COORDINATION OF BACK-TO-BACK H USING A MATLAB SIMULINK SOFTWARE. A MATLAB SIMPOWERSYSTEMS TOOLBOX, PROVI MATLAB SIMULINK SOFTWARE WILL BE USED TO DEVELOP THE POWER CONVERTER AND CON THE SIMULATION WILL SHOW HOW IT WILL RESPOND TO THE MODULATION SIGNAL GENE CONTROLLERS. THE RESULT OF THE SIMULATIONS WILL HELP TO IMPROVE THE SYSTEM DYN AND IMPROVE THE TRANSFER CAPACITY.

1.2 PROBLEM STATEMENT

HVDC SYSTEM IS GETTING MORE IMPORTANT IN POWER TRANSMISSION SYSTEM TECH DUE TO THE ADVANTAGES COMPARE TO THE AC TRANSMISSION SYSTEM. THE HVDC START INVENTION OF A MERCURY-ARC RECTIFIER WHICH IS USED IN THE LINE-COMMUTATED CURREN CONVERTER. THE MERCURY-ARC RECTIFIER IS THEN REPLACED BY THE THYRISTOR VALVES NEXT DEVELOPMENT IN HVDC SYSTEM. INNOVATION IN ALMOST EVERY AREA OF HVDC SYST HAVE BEEN CONSTANTLY ADDING TO IMPROVE THE RELIABILITY OF THE SYSTEM AND PROVI BENEFIT TO USERS. RECENTLY THE HVDC TECHNOLOGY BECOMES MORE EXPAND THE US INSULATED GATE BIPOLAR TRANSISTOR (IGBT) IN SELF-COMMUTATED VOLTAGE SOURCE C (VSC). THE MAIN CHARACTERISTICS OF VSC ARE COMPACT DESIGN, FOUR QUADRANT OPER HIGH LOSSES. THE VSC WILL CREATE MORE DYNAMICS FOR BETTER POWER QUALITY SYSTEM

IS ANOTHER PROBLEM OCCUR. THE IGBT SWITCHING FREQUENCY IS MUCH FASTER (>10
COMPARE TO THE THYRISTOR SWITCHING FREQUENCY AROUND 50-60HZ. THIS WILL REQUIR
POWER CONVERTER AND CONTROL SYSTEM OF SIGNAL MODULATION GENERATION. THIS
EXPECTED TO OVERCOME THE PROBLEM BY DEVELOPING THE COORDINATED CONTROL OF B
HVDC LINK BY USING MATLAB SIMULINK SOFTWARE.

1.3 AIM

- TO DEVELOP A COORDINATED CONTROL OF BACK-TO-BACK HVDC LINK USING MATLAB S
  SOFTWARE.

1.4 RESEARCH OBJECTIVES

THE SCOPES OF THIS RESEARCH ARE AS FOLLOWS:

1. TO DESIGN VSC 1 AS CONSTANT DC SOURCE.
2. TO DESIGN VSC 2 AS CONSTANT DC SOURCE PLUS AN EXTERNAL DC CABLE CURRENT LOOP.
3. TO ESTABLISH POWER FLOW THROUGH THE HVDC LINK AND ANALYZE THE RESULT.

1.5 RESEARCH METHODOLOGY

THERE ARE FEW STEPS OF METHODOLOGY THAT WILL BE USED IN THIS PROJECT. THE IS TO MODEL THE POWER SYSTEM AND DETERMINE THE TRANSFER FUNCTION OF EACH CON HVDC SYSTEM. THE MODEL SHOULD BE KEPT AS SIMPLE AS POSSIBLE WHILE STILL CAPT IMPORTANT ELEMENT OF THE SYSTEM. THERE IS TWO MAIN BLOCKS OF A POWER CONVERTEF VSC1 (VSC FOR NETWORK 1) AND VSC2 (VSC FOR NETWORK 2).

THE VSC1 DESIGN STARTS BY DEVELOPING THE AC CURRENT CONTROLLER. BASED CLASSICAL CONTROL SYSTEM DESIGN TECHNIQUE, THE CONTROL LOOP, AND CONTROL PARA DETERMINED. THE CURRENT CONTROLLER SHOULD BE ABLE TO RESPOND TO AN ACTIVE A POWER DEMAND. A SUITABLE CURRENTS VALUE WILL BE INJECTED INTO THE AC GRID TC RESPONSE. THE DESIGNED CONTROLLER ALSO SHALL BE ABLE TO BE USED IN THE D-Q FRAME

THE AC CURRENT CONTROLLER IS THEN SHALL BE ENHANCED BY INCLUDING THE PHASI LOOP (PLL) FOR THE PURPOSE OF GRID SYNCHRONIZATION. A D-Q PLL IS CHOSEN TO BE USED PROJECT DESIGN BECAUSE IT IS THE SIMPLEST CHOICE AVAILABLE. ONCE THE DESIGN COMP AT THIS STAGE, THE POWER CONVERTER SHOULD BE ABLE TO CONTROL THE AC GRID ACTI POWER AT DESIRED VALUE.

THE COMPLETED MODEL ABOVE IS THEN WILL BE EXTENDED WITH DC VOLTAGE CONT IS THE END PART OF VSC1. THE DC VOLTAGE CONTROLLER SHALL BE ABLE TO CONTROL D A CONSTANT VALUE EVEN THOUGH THE LOAD RESISTOR VALUE IS CHANGE.

AFTER COMPLETE THE VS1 DESIGN PART, THE VSC2 DESIGN WILL START WITH DC LOOP. THE FUNCTION OF THE CONTROL LOOP IS TO CONTROL CURRENT THAT FLOW THROU

HENCE CONTROL THE POWER TRANSMITTED THROUGH BACK-TO-BACK LINK SINCE THE CURRE RELATION IS PROPORTIONAL. IN THE DC CURRENT LOOP, THERE WILL BE DC VOLTAGE AS TH THE CURRENT CONTROLLER OUTPUT WILL PROVIDE A REFERENCE VOLTAGE FOR THE DC VO LOOP. DURING DESIGN THIS CONTROLLER, THE VSC1 WILL BE CONSIDERED AS AN IDEAL VOL TO THE HVDC CABLE FOR DESIGN SIMPLICITY.

ONCE THE VSC1 AND VSC2 DESIGN ARE COMPLETED, THE MODEL OF FULLY CONTRO BACK-TO-BACK HVDC SYSTEM WILL BE IMPLEMENTED. FINALLY, THE PERFORMANCE O EXAMINED AND ANALYZE BY SIMULATION USING MATLAB SIMULINK. THE SIMULATION RESU SHOW THE RESPONSE OF DC AND AC CURRENT, VOLTAGE AND POWER WHEN THE DC CURRENT IS CHANGED. THE SWITCHING VERSION OF THE FULL BACK-TO-BACK HVDC SYSTEM W IMPLEMENTED USING THE SAME CONTROLLER THAT HAVE BEEN DESIGNED.

1.6 SYSTEM DELIVERABLES

THIS PROJECT WILL DEVELOP THE CONTROL SYSTEM MODEL OF BACK-TO-BACK HVDC LINK. CONTROL PARAMETER SHALL BE DETERMINED USING THE CLASSICAL CONTROL SYSTEM DESIGN T PRESENT THE SIMULATION RESULT OF THE DESIGN AND EVALUATION OF THE PROPOSED CONTROLL BACK HVDC LINK. THEN, THE SIMULATION RESULT WILL BE DISCUSSED AND ANALYZE.

CHAPTER 2

LITERATURE REVIEW

2.1 AN OVERVIEW OF HVDC SYSTEM

A HIGH VOLTAGE DIRECT CURRENT (HVDC) TECHNOLOGIES ARE KEEP DEVELOP TIME TO TIME. THE HVDC TECHNOLOGIES ARE STARTED WITH SO CALLED HVDC "CLAS THYRISTOR AS ITS SWITCHING COMPONENT. IT ONLY HAS TURN-ON CAPABILITY WHIC DISADVANTAGES. THUS, THE CLASSIC HVDC IS ALSO KNOWN AS LINE-COMMUTATED CU CONVERTER (LCC/ CSC) [11]. THE HVDC TECHNOLOGIES ARE THEN HAS BEEN IMPRO HVDC "PLUS" BY CHANGING THE SWITCHING COMPONENT FROM THYRISTOR TO IGBT BEC CAPABILITY OF IGBT THAT CAN TURN-ON AND OFF. THIS TECHNOLOGY IS ALSO COMMUTATED VOLTAGE-SOURCE CONVERTER (SCC/ VSC) [11].

THE FULLY CONTROLLED SEMICONDUCTOR DEVICES AVAILABLE TODAY FOR HIG POWER CONVERTERS CAN BE BASED ON EITHER THYRISTOR OR TRANSISTOR TECHNOL [1]:

ACRONYM	TYPE	FULL NAME
IGBT	TRANSISTOR	INSULATED GATE BIPOLAR TRANSISTOR
IEGT	TRANSISTOR	INJECTION ENHANCED GATE TRANSISTOR
GTO	THYRISTOR	GATE TURN-OFF THYRISTOR
IGCT	THYRISTOR	INTEGRATED GATE COMMUTATED THYRISTOR
GCT	THYRISTOR	GATE COMMUTATED TURN-OFF THYRISTOR

TABLE 2.1: SUMMARY OF FULLY CONTROLLED HIGH-POWER SEMICONDUCTO

TYPICALLY A VSC WHICH IS USE IGBT AS IT SWITCHING COMPONENT APPLY PULS MODULATION (PWM) OPERATING AT A HIGHER FREQUENCY THAN THE LINE FREQUEN CAUSE HIGHER SWITCHING LOSSES. FIGURE 2.1 INDICATES THE TYPICAL LOSSES DEP SWITCHING FREQUENCY [11]:

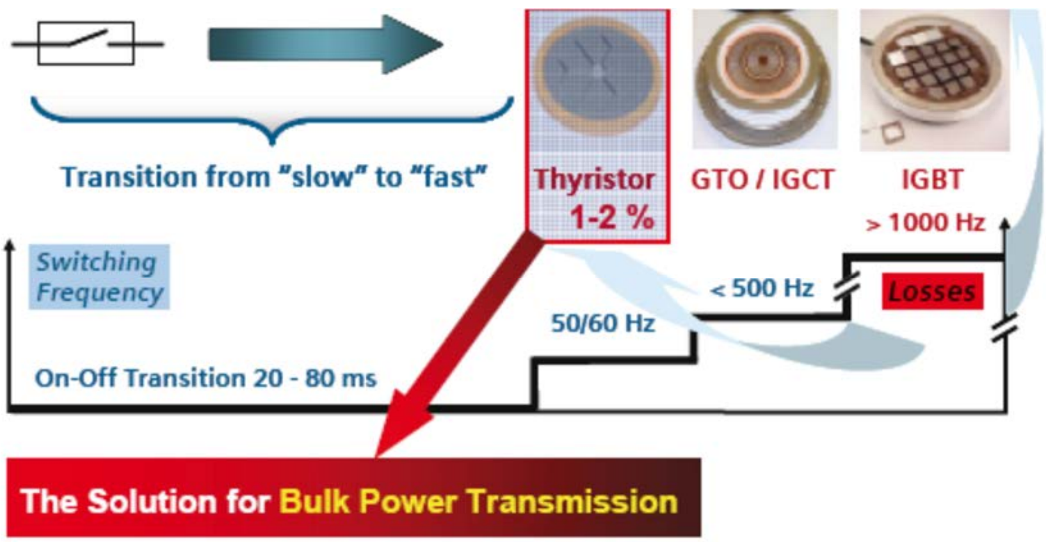

FIGURE 2.1: POWER ELECTRONICS FOR HVDC [11]

THE HIGH FREQUENCY OF PWM OPERATION IS DIRECTLY PROPORTIONAL TO TH LOSSES AND IT WILL REQUIRE A BETTER HEAT SINK DESIGN. THIS IS ONE OF THE MO CHALLENGING ISSUES THAT NEED TO BE DEALT WITH IN VSC-BASED HIGH-POWER APPL DISADVANTAGES IF USING VSC ARE THE ELECTROMAGNETIC COMPATIBILITY/EL INTERFERENCE (EMC/EMI), TRANSFORMER INSULATION STRESSES, AND HIGH-FREQUEN WHICH WILL REQUIRE ADDITIONAL FILTERS [1].

ALTHOUGH FACING MANY CHALLENGES, THE HVDC TECHNOLOGIES KEEP ON G ORDER TO FULFILL THE POWER DEMAND THAT RISES EVERY YEAR. RISING DEMAND WIL POWER TO BE CARRIED OUT BY THE TRANSMISSION LINE. CURRENTLY, THE HIGHEST F STATION IS THE ITAIPU POWER STATION WHICH IS RATED AT 12.6GW, 600KV. THE ITAI STATION IS CONSIDERED AS THE ULTRA HIGH VOLTAGE DIRECT CURRENT (UHVDC) BE POWER RATING ABOVE 10GW. IN THE LATEST TECHNOLOGY, CHINA IS CURRENTLY BEIN THE POSSIBILITY OF USING THE UHVDC WITH VOLTAGE RATING IS 1,100KV FOR POWER TR OF 10 TO 13 GW PER LINE FOR DISTANCES OVER 2,000 KM [13]. NEW TECHNOLOGIES WIL NEW CHALLENGES IN TERM OF COMPONENTS, CONTROL, PROTECTION, CABLES AND SO

2.2 FUNDAMENTAL OF VSC-HVDC SYSTEM

CURRENTLY, THERE IS TWO TECHNOLOGY OF HVDC SYSTEM. FIRSTLY IS THE CSC-H THE OTHER ONE IS VSC-HVDC. FIGURE 2.2 SHOWS THE BASIC DIAGRAM OF CSC-HVDC FIGURE 2.3 SHOWS THE BASIC DIAGRAM OF VSC-HVDC [1][2]:

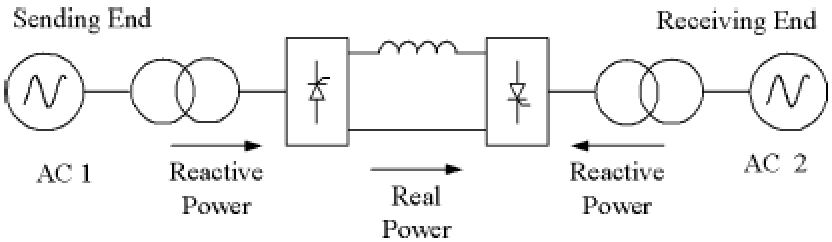

FIGURE 2.2: HVDC SYSTEM BASED ON CSC TECHNOLOGY WITH THYRISTORS

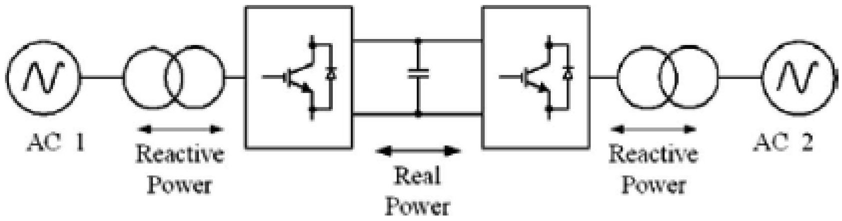

FIGURE 2.3: HVDC SYSTEM BASED ON VSC TECHNOLOGY WITH IGBTS

THE MAIN DIFFERENCE OF BOTH OF THE TECHNOLOGY IS THE SWITCHING COMPONENT T THYRISTOR IS USED IN CSC WHILE IGBT IS USED IN VSC TECHNOLOGY.

2.3 VSC-HVDC SYSTEM CONFIGURATION

VSC-HVDC CAN BE CONFIGURED TO SEVERAL TYPES OF TOPOLOGY/SCHEME SUCH TO-BACK HVDC SYSTEM, MONOPOLAR HVDC SYSTEM, BIPOLAR HVDC SYSTEM AND M TERMINAL HVDC SYSTEM [1][2][12].

2.3.1 BACK TO BACK VSC-HVDC SYSTEM

WITH THIS CONFIGURATIONS, THE CONVERTERS (RECTIFIER AND INVERTER) ARE LOCA STATIONS. THIS CONFIGURATION IS USED TO INTERCONNECT TWO AC SYSTEM WHICH FREQUENCY OR DIFFERENT FREQUENCY (ASYNCHRONOUS INTERCONNECTION). FIGUR BASIC DIAGRAM FOR BACK-TO-BACK HVDC SYSTEM.

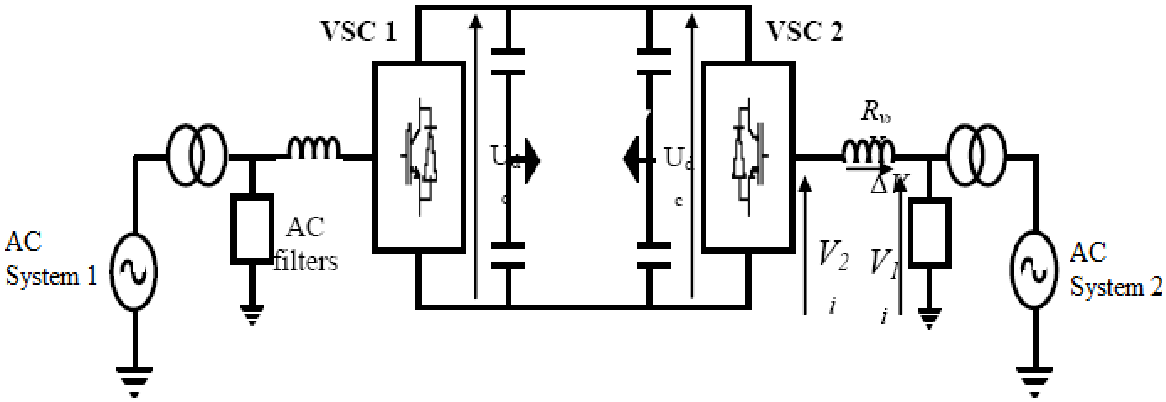

FIGURE 2.4: BASIC BACK-TO-BACK VSC HVDC SYSTEM [3]

2.3.2 MONOPOLAR VSC-HVDC SYSTEM

THIS CONFIGURATION IS USUALLY USED FOR VERY LONG DISTANCES TRANSMISS INVOLVED VERY LONG SEA CABLE TRANSMISSION WHICH WILL REQUIRE SUBMAR CONNECTION. THE GROUND ELECTRODES ARE USE FOR THE RETURN PATH OF THE CUR

2.3.3 BIPOLAR VSC-HVDC SYSTEM

A BIPOLAR HVDC SYSTEM IS A COMBINATION OF TWO MONOPOLAR SYSTEMS. IT I USED IF THE POWER OR TRANSMISSION CAPACITY EXCEEDS THE SINGLE POLE CAPA POWER CAPACITY WILL BE SPLIT INTO TWO POLES WITH EACH POLE COVER 50% OF THE THE ADVANTAGE OF THIS CONFIGURATION, IT IS STILL ABLE TO PROVIDE 50% OF POW DURING THE MAINTENANCE OF ONE OF THE POLE.

2.3.4 MULTI-TERMINAL VSC-HVDC SYSTEM

THIS CONFIGURATION IS THE COMBINATION OF MORE THAN TWO SETS OF THE BI THIS CONFIGURATION IS APPLIED IN A LARGE GRID WHICH CAN OFFER MORE ECON TRANSMISSION LINE AND PROVIDE BETTER FLEXIBILITY IN POWER DISPATCH AND STA AC SYSTEM [7].

2.4 CONTROLLER IN BACK TO BACK VSC-HVDC SYSTEM

THE CONTROLLER OF THE VSC-HVDC SYSTEM FOR CONVERTER 1 (RECTIFIER) AN 2 (INVERTER) CONTROLLER DESIGN ARE IDENTICAL BUT BOTH CONVERTER CONT COMMUNICATION BETWEEN THEM AND OPERATE INDEPENDENTLY. THERE IS FOUR MAI

A. CURRENT CONTROLLER (INNER LOOP)

THE CURRENT CONTROLLER IS THE INNER LOOP OF THE ACTIVE AND RE CONTROLLER. THE INNER LOOP RESPONSE SHALL BE FASTER THAN THE OUTE D-Q CURRENT COMPONENT TO CONTROL AC CURRENT IN CASE OF THE CHA CURRENT THAT MAY CAUSE THE LOAD CHANGES OR FAULT. THE D-Q COMPON ORDER PLANT AND BOTH ARE INDEPENDENTLY RELATED [3].

B. ACTIVE POWER CONTROLLER (OUTER LOOP)

THE ACTIVE POWER CONTROLLER IS USED TO KEEP THE POWER TRANSMITTE LINK AT THE REFERENCE VALUE, P_{REF}. IN ORDER TO CONTROL THE ACTIVE POWER FLOW C VOLTAGE LEVEL, THE ACTIVE CURRENT I_D SHALL BE USED IN THE INNER CURRENT LOOP CON [8].