APPENDIX-1

DSO recorded waveforms for 2-Level Inverter fed IM and FFT analysis for CM voltage and Phase voltage for all other frequencies (both in volts and dBµV)

Fig. A. Input to Motor (20ms/Div). Ch 1: 200 : 1 waveform of Star point of IM to Gnd. Ch 2: 200 : 1 waveform of Line voltage to IM. Ch 3: 20 : 1 waveform of Vector sum of Ph current in terms of voltage. Ch 4: 1 : 1 Ph current in terms of voltage.

Fig. B. Input to Motor (20ms/Div). Ch 1: 200 : 1 waveform of Phase voltage to IM. Ch 2: 200 : 1 waveform of Line voltage to IM. Ch 3: 20 : 1 waveform of Vector sum of current in terms of voltage. Ch 4: 1 : 1 One phase current in terms of voltage.
Fig. 9. Star point of IM to ground
Recorded (1msec/Div)

Fig. 10. Star point of IM to ground
Recorded (500μsec/Div)

Fig. 11. Star point of IM to ground
Recorded (500μsec/Div)

Fig. 12. Star point of IM to ground
Recorded (200μsec/Div)

Fig. 13. Star point of IM to ground
Recorded (200μsec/Div)

Fig. 14. Star point of IM to ground
Recorded (100μsec/Div)

Fig. 15. Star point of IM to ground
Recorded (100μsec/Div)

Fig. 16. Star point of IM to ground
Recorded (50μsec/Div)
Fig. 25. Star point of IM to ground
Recorded (2µsec/Div)

Fig. 26. Star point of IM to ground
Recorded (1µsec/Div)

Fig. 27. Star point of IM to ground
Recorded (1µsec/Div)

Fig. 28. Star point of IM to ground
Recorded (500 nsec/Div)

Fig. 29. Star point of IM to ground
Recorded (500 nsec/Div)

Fig. 30. Star point of IM to ground
Recorded (200 nsec/Div)
Fig. 31. Star point of IM to ground
Recorded (200 nsec/Div)

Fig. 34. Star point of IM to ground
Recorded (50 nsec/Div)

Fig. 32. Star point of IM to ground
Recorded (100 nsec/Div)

Fig. 35. Star point of IM to ground
Recorded (50 nsec/Div)

Fig. 33. Star point of IM to ground
Recorded (100 nsec/Div)

Fig. 36. Star point of IM to ground
Recorded (20 nsec/Div)
Fig. 37. Star point of IM to ground
Recorded (20 nsec/Div)

Fig. 38. Star point of IM to ground
Recorded (10 nsec/Div)

Fig. 39. Star point of IM to ground
Recorded (10 nsec/Div)

Fig. 40. Star point of IM to ground
Recorded (5 nsec/Div)

Fig. 41. Star point of IM to ground
Recorded (5 nsec/Div)

Fig. 42. Star point of IM to ground
Recorded (2 nsec/Div)
Fig. 43. Star point of IM to ground
Recorded (2nsec/Div)

Fig. 44. Star point of IM to ground
Recorded (1nsec/Div)

Fig. 45. Star point of IM to ground
Recorded (1nsec/Div)

Fig. 46. Phase voltage to Induction Motor. (Recorded 20msec/Div)

Fig. 47. Phase voltage to Induction Motor. (Recorded 20msec/Div)

Fig. 48. Phase voltage to Induction Motor. (Recorded 10msec/Div)
Fig. 49. Phase voltage to Induction Motor. (Recorded 10 msec/Div)

Fig. 50. Phase voltage to Induction Motor. (Recorded 5 msec/Div)

Fig. 51. Phase voltage to Induction Motor. (Recorded 2 msec/Div)

Fig. 52. Phase voltage to Induction Motor. (Recorded 2 msec/Div)

Fig. 53. Phase voltage to induction Motor. (Recorded 1 msec/Div)

Fig. 54. Phase voltage to Induction Motor. (Recorded 1 msec/Div)
Fig. 55. Phase voltage to Induction Motor. (Recorded 500 µ sec/Div)

Fig. 56. Phase voltage to Induction Motor. (Recorded 500 µ sec/Div)

Fig. 57. Phase voltage to Induction Motor. (Recorded 200 µ sec/Div)

Fig. 58. Phase voltage to Induction Motor. (Recorded 200 µ sec/Div)

Fig. 59. Phase voltage to Induction Motor. (Recorded 100 µ sec/Div)

Fig. 60. Phase voltage to Induction Motor. (Recorded 100 µ sec/Div)
Fig. 61. Phase voltage to Induction Motor. (Recorded 50 µ sec/Div)

Fig. 62. Phase voltage to Induction Motor. (Recorded 50 µ sec/Div)

Fig. 63. Phase voltage to Induction Motor. (Recorded 20 µ sec/Div)

Fig. 64. Phase voltage to Induction Motor. (Recorded 20 µ sec/Div)

Fig. 65. Phase voltage to Induction Motor. (Recorded 10 µ sec/Div)

Fig. 66. Phase voltage to Induction Motor. (Recorded 10 µ sec/Div)
Fig. 67. Phase voltage to Induction Motor. (Recorded 5 µ sec/Div)

Fig. 68. Phase voltage to Induction Motor. (Recorded 5 µ sec/Div)

Fig. 69. Phase voltage to Induction Motor. (Recorded 2 µ sec/Div)

Fig. 70. Phase voltage to Induction Motor. (Recorded 2 µ sec/Div)

Fig. 71. Phase voltage to Induction Motor. (Recorded 1 µ sec/Div)

Fig. 72. Phase voltage to Induction Motor. (Recorded 1 µ sec/Div)
Fig. 73. Phase voltage to Induction Motor. (Recorded 500 n sec/Div)

Fig. 74. Phase voltage to Induction Motor. (Recorded 200 n sec/Div)

Fig. 75. Phase voltage to Induction Motor. (Recorded 200 n sec/Div)

Fig. 76. Phase voltage to Induction Motor. (Recorded 200 n sec/Div)

Fig. 77. Phase voltage to Induction Motor. (Recorded 100 n sec/Div)

Fig. 78. Phase voltage to Induction Motor. (Recorded 100 n sec/Div)
APPENDIX-2

DSO recorded waveforms for 3- Level Inverter fed IM and FFT analysis for phase voltage, Line voltage and the shaft voltage for all other frequencies upto 500000Hz(both in volts and dBµV)

Anlg Ch State  Units/Div  Position  Coupling  BW Limit  Invert
Ch 1:  On  2.00V/  -4.57600V  AC  Off  Off
Ch 2:  On  2.00V/  -600.00mV  AC  Off  Off
Ch 3:  On  1.00V/  1.92500V  DC  Off  Off

Anlg Ch Impedance  Probe
Ch 1:  1M Ohm  200 : 1 Phase voltage.
Ch 2:  1M Ohm  200 : 1 Line voltage
Ch 3:  1M Ohm  200 : 1 Shaft Voltage with respect to gnd.

Trigger Mode  Coupling  Noise Rej  HF Reject  Holdoff
Edge Normal  DC  Off  Off  60ns
Trigger Source  Slope
Edge  2,8  Rising
Time  Time Ref  Main s/div  Delay
Normal  Left  20.00ms/  0.0s
Acquisition Realtime  Vectors  Inf Persist
Normal  On  On  Off
Fig. 1. FFT of Phase voltage (three level Inverter, 20ms/Div)

Fig. 2. FFT Phase voltage (X-Y Expanded, 20ms/Div)

Fig. 3. FFT of Phase voltage in dBµV (20ms/Div)

Fig. 4. FFT of Phase Voltage in dBµV (20ms/Div X-Y Expanded)

Fig. 5. FFT of line voltage in volts (20ms/Div)

Fig. 6. FFT of line voltage in volts (X-Y Expanded, 20ms/Div)
Fig. 7. FFT of line voltage in dBµV (20ms/Div)

Fig. 8. FFT of line voltage in dBµV (20ms/Div, X-Y Expanded)

Fig. 9. FFT of shaft voltage in volts (20ms/Div)

Fig. 10. FFT of shaft voltage in volts (20ms/Div, X-Y Expanded)

Fig. 11. FFT of shaft voltage in dBµV (20ms/Div)

Fig. 12. FFT of shaft voltage in dBµV (20ms/Div, X-Y Expanded)
Fig 13. FFT of phase voltage in volts (10ms/Div)

Fig 14. FFT of phase voltage in volts (10ms/Div X-Y Expanded)

Fig 15. FFT of Phase voltage in dBµV (10ms/Div)

Fig 16. FFT of Phase voltage in dBµV (X-Y Expanded, 10ms/Div)

Fig 17. FFT of Line Voltage (10ms/Div)

Fig 18. FFT of Line voltage (X-axis expanded, 10ms/Div)
Fig. 19. FFT of Line voltage in dB µV (10ms/Div)

Fig. 20. FFT of Line voltage in dB µV (X-axis expanded, 10ms/Div)

Fig. 21. FFT of Shaft voltage in volts (10ms/Div)

Fig. 22. FFT of Shaft Voltage in volts (X-Y Expanded, 10ms/Div)

Fig. 23. FFT of Shaft voltage in dBµV (10ms/Div)

Fig. 24. FFT of Shaft voltage in dBµV (X-Y expanded, 10ms/Div)
Fig. 25. FFT of phase voltage in volts (5ms/Div)

Fig. 26. FFT of phase voltage in volts (5ms/Div, X-Y expanded)

Fig. 27. FFT of phase voltage in dBµvolts (5ms/Div)

Fig. 28. FFT of phase voltage in dBµvolts (5ms/Div, X-Y expanded)

Fig. 29. FFT of Line voltage in volts (5ms/Div)

Fig. 30. FFT of Line voltage in volts (5ms/Div, X-Axis expanded)
Fig. 31. FFT of line voltage in dB µV(5ms/Div)

Fig. 32. FFT of line voltage in dB µV(5ms/Div, X-Axis expanded)

Fig. 33. FFT of Shaft voltage in volts(5ms/Div)

Fig. 34. FFT of Shaft voltage in volts (X-Axis Expanded, 5ms/Div)

Fig. 35. FFT of Shaft voltage in dBµV(5ms/Div)

Fig. 36. FFT of Shaft voltage in dBµV(X-Axis expanded, 5ms/Div)
Fig. 37. FFT of Phase voltage in volts (2ms/Div)

Fig. 38. FFT of Phase voltage in volts (X axis expanded, 2ms/Div)

Fig. 39. FFT of Phase voltage in dBµV (2ms/Div)

Fig. 40. FFT of Phase voltage in dBµV (Y-axis expanded, 2ms/Div)

Fig. 41. FFT of line voltage in volts (2ms/Div)

Fig. 42. FFT of line voltage in volts (2ms/Div)
Fig. 43. FFT of line voltage in dB µV (2ms/Div)

Fig. 44. FFT of line voltage in dBµV (X-Y expanded, 2ms/Div)

Fig. 45. FFT of shaft voltage in volts (2ms/Div)

Fig. 46. FFT of shaft voltage in volts (Y axis expanded, 2ms/Div)

Fig. 47. FFT of shaft voltage in dBµV (2ms/Div)

Fig. 48. FFT of shaft voltage in dBµV (Y-axis expanded, 2ms/Div)
Fig. 49. FFT of Phase voltage in volts (1ms/Div)

Fig. 50. FFT of Phase voltage in volts (1ms/Div, Y-axis expanded)

Fig. 51. FFT of phase voltage in dBµV (1ms/Div)

Fig. 52. FFT of phase voltage in dBµV (Y-axis expanded, 1ms/Div)

Fig. 53. FFT of Line voltage in volts (1ms/Div)

Fig. 54. FFT of Line voltage in volts (1ms/Div, Y-axis expanded)
Fig. 55. FFT of Line voltage in dBµV (1ms/Div)

Fig. 56. FFT of Line voltage in dBµV (Y axis expanded, 1ms/Div)

Fig. 57. FFT of Shaft voltage in volts (1ms/Div)

Fig. 58. FFT of Shaft voltage in volts (1ms/Div, Y-axis expanded)

Fig. 59. FFT of Shaft voltage in dBµV (1ms/Div)

Fig. 60. FFT of Shaft voltage in dBµV (Y axis expanded, 1ms/Div)
Fig. 61. FFT of phase voltage in volts (500 µs/Div)

Fig. 62. FFT of phase voltage in volts (500 µs/Div, Y-axis expanded)

Fig. 63. FFT of phase voltage in dB µvolts (500 µs/Div)

Fig. 64. FFT of phase voltage in dB µvolts (500 µs/Div, Y-axis expanded)

Fig. 65. FFT of line voltage in volts (500 µs/Div)

Fig. 66. FFT of line voltage in volts (500 µs/Div, Y-axis expanded)
Fig. 67. FFT of line voltage in dB µvolts (500µs/Div)

Fig. 68. FFT of line voltage in dB µvolts (500µs/Div, expanded view)

Fig. 69. FFT of Shaft voltage in volts (500µs/Div)

Fig. 70. FFT of Shaft voltage in volts (500µs/Div, Y-axis expanded)

Fig. 71. FFT of Shaft voltage in dB µvolts (500µs/Div)

Fig. 72. FFT of Shaft voltage in dB µvolts (500µs/Div, expanded view)
Fig. 73. FFT of Phase voltage in volts (200µs/Div)

Fig. 74. FFT of Phase voltage in volts (200µs/Div, expanded view)

Fig. 75. FFT of Phase voltage in dB µvolts (200µs/Div)

Fig. 76. FFT of Phase voltage in dB µvolts (200µs/Div, expanded view)

Fig. 77. FFT of line voltage in volts (200µs/Div)

Fig. 78. FFT of line voltage in volts (200µs/Div, expanded view)
Fig. 79. FFT of line voltage in dB µvolts (200µs/Div)

Fig. 80. FFT of line voltage in dB µvolts (200µs/Div, expanded view)

Fig. 81. FFT of Shaft voltage in volts (200µs/Div)

Fig. 82. FFT of Shaft voltage in volts (200µs/Div, expanded view)

Fig. 83. FFT of Shaft voltage in dB µvolts (200µs/Div)

Fig. 84. FFT of Shaft voltage in dB µvolts (200µs/Div expanded view)
Fig. 85. FFT of Phase voltage in volts (100µs/Div)

Fig. 86. FFT of Phase voltage in volts (100µs/Div, Y-axis expanded)

Fig. 87. FFT of Phase voltage in dB µvolts (100µs/Div)

Fig. 88. FFT of Phase voltage in dB µvolts (100µs/Div expanded view)

Fig. 89. FFT of line voltage in volts (100µs/Div)

Fig. 90. FFT of line voltage in volts (100µs/Div, Y-axis expanded)
Fig. 91. FFT of Line voltage in dB µvolts (100µs/Div)

Fig. 92. FFT of Line voltage in dB µvolts (100µs/Div, Y-axis expanded)

Fig. 93. FFT of Shaft voltage in volts (100µs/Div)

Fig. 94. FFT of Shaft voltage in volts (100µs/Div, Y axis expanded)

Fig. 95. FFT of Shaft voltage in dB µvolts (100µs/Div)

Fig. 96. FFT of Shaft voltage in dB µvolts (100µs/Div, Y-axis expanded)
APPENDIX-3

DSO recorded waveforms for 5-Level Inverter fed IM and FFT analysis for phase voltage, CM voltage and the shaft voltage for all other frequencies upto 500000Hz (both in volts and dBµV)

Anlg Ch State Units/Div Position Coupling BW Limit Invert
Ch 1: On 2.00V/ -5.00000V AC Off Off
Ch 2: On 1.00V/ -325.00mV DC Off Off
Ch 3: On 10.0V/ 13.2500V DC Off Off
Ch 4: On 2.00V/ 5.40000V AC Off Off
Anlg Ch Impedance Probe
Ch 1: 1M Ohm 200 : 1 Phase voltage to IM (2V/div)
Ch 2: 1M Ohm 200 : 1 CM voltage (1V/div)
Ch 3: 1M Ohm 1 : 1 Shaft voltage (10V/Div)
Ch 4: 1M Ohm 1 : 1 Bearing current in terms of voltage using current probe (2V/div)
Trigger Mode Coupling Noise Rej HF Reject Holdoff
Edge Normal DC Off Off 60ns
Trigger Source Slope
Edge 2,8 Rising
Time Time Ref Main s/div Delay
Normal Left 20.00ms/ 0.0s
Acquisition Realtime Vectors Inf Persist
Normal On On Off
Note:- Dt. 17-7-2011. IM running successfully at 450Vdc input to inverter Bridge.
Fig. 1. Phase voltage applied to IM (20ms/DIV)

Fig. 2. Phase voltage applied to IM (Expanded view, 20ms/Div)

Fig. 3. FFT of phase voltage applied to IM in dBµV. (20ms/Div)

Fig. 4. FFT of phase voltage to IM in dB µV. (Expanded view, 20ms/Div)

Fig. 5. FFT of CM voltage of IM in volts. (20ms/Div)

Fig. 6. FFT of CM voltage of IM in volts. (Expanded view, 20ms/Div)

Fig. 7. FFT of CM voltage of IM in dBµV (20ms/Div)

Fig. 8. FFT of CM voltage of IM in dBµV (Expanded view, 20ms/Div)
Fig. 9. FFT of Bearing current in amps (20ms/Div)

Fig. 10. FFT of Bearing current in amps (Expanded view, 20ms/Div)

Fig. 11. FFT of Bearing current in dB µA (20ms/Div)

Fig. 12. FFT of Bearing current in dB µA (Expanded view, 20ms/Div)

Fig. 13. FFT of Phase voltage applied to IM (10ms/Div)

Fig. 14. FFT of Phase voltage to IM (Expanded view, 10ms/Div)
Fig. 15. FFT of Phase voltage to IM in dB µV (10ms/Div)

Fig. 16. FFT of Phase voltage to IM in dB µV (Expanded view, 10ms/Div)

Fig. 17. FFT of Shaft voltage of IM in volts (10ms/Div)

Fig. 18. FFT of Shaft voltage of IM in volts (Expanded, 10ms/Div)

Fig. 19. FFT of Shaft voltage of IM in dBµV (10ms/Div)

Fig. 20. FFT of Shaft voltage of IM in dBµV (Expanded, 10ms/Div)
Fig. 21. FFT of Bearing current of IM in amps (10ms/Div)

Fig. 22. FFT of Bearing current of IM in amps (Expanded, 10ms/Div)

Fig. 23. FFT of Bearing current of IM in dBμA (10ms/Div)

Fig. 24. FFT of Bearing current of IM in dBμA (Expanded, 10ms/Div)

Fig. 25. FFT of Phase voltage to IM in volts (5ms/Div)

Fig. 26. FFT of Phase voltage to IM in volts (Expanded, 5ms/Div)
Fig. 27. FFT of Phase voltage to IM in dB µV (5ms/Div)

Fig. 28. FFT of Phase voltage to IM in dB µV (Expanded, 5ms/Div)

Fig. 29. FFT of CM voltage of IM (5ms/Div)

Fig. 30. FFT of CM voltage of IM (Expanded, 5ms/Div)

Fig. 31. FFT of CM voltage of IM in dBµV (5ms/Div)

Fig. 32. FFT of CM voltage of IM in dBµV (Expanded, 5ms/Div)
Fig. 33. FFT of Bearing current in amps (5ms/Div)

Fig. 34. FFT of Bearing current in amps (expanded view, 5ms/Div)

Fig. 35. FFT of Bearing current in dBμA (5ms/Div)

Fig. 36. FFT of Bearing current in dBμA (Expanded view, 5ms/Div)

Fig. 37. FFT of Phase voltage to IM (2ms/Div)

Fig. 38. FFT of Phase voltage to IM (Expanded view, 2ms/Div)
Fig. 39. FFT of Phase voltage to IM in dBµV (2ms/Div)

Fig. 40. FFT of Phase voltage to IM in dBµV (Expanded view, 2ms/Div)

Fig. 41. FFT of CM voltage of IM (2ms/Div)

Fig. 42. FFT of CM voltage of IM in dB µV (2ms/Div)

Fig. 43. FFT of CM voltage of IM in dB µV (Expanded view, 2ms/Div)

Fig. 44. FFT of Bearing current of IM in amps (2ms/Div)
Fig. 45. FFT of Bearing current of IM in amps (Expanded view, 2ms/Div)

Fig. 46. FFT of Bearing current of IM in dB µA (2ms/Div)

Fig. 47. FFT of Bearing current of IM in dB µA (Expanded view, 2ms/Div)

Fig. 48. FFT of Phase voltage of IM in volts (1ms/Div)

Fig. 49. FFT of Phase voltage of IM in volts (Expanded, 1ms/Div)

Fig. 50. FFT of phase voltage of IM in dBµV (1ms/Div)
Fig. 51. FFT of phase voltage of IM in dBµV (Expanded, 1ms/Div)

Fig. 52. FFT of CM voltage of IM in volts (1ms/Div)

Fig. 53. FFT of CM voltage of IM in dBµV (Expanded, 1ms/Div)

Fig. 54. FFT of CM voltage of IM in dBµV (Expanded, 1ms/Div)

Fig. 55. FFT of Bearing current in amps (1ms/Div)

Fig. 56. FFT of Bearing current in amps (Expanded view, 1ms/Div)
Fig. 57. FFT of Bearing current in dBµA (1ms/Div)

Fig. 58. FFT of Bearing current in dBµA (Expanded view, 1ms/Div)

Fig. 59. FFT of Phase voltage of IM (500µs/Div)

Fig. 60. FFT of Phase voltage of IM (Expanded view, 500µs/Div)

Fig. 61. FFT of Phase voltage of IM in dBµV (500µs/Div)

Fig. 62. FFT of Phase voltage of IM in dBµV (Expanded view, 500µs/Div)
Fig. 63. FFT of CM voltage to IM (500µs/Div)

Fig. 64. FFT of CM voltage of IM in dBµV (500µs/Div)

Fig. 65. FFT of CM voltage of IM in dBµV (Expanded view, 500µs/Div)

Fig. 66. FFT of Bearing current of IM in amps (500µs/Div)

Fig. 67. FFT of Bearing current of IM in amps (Expanded view, 500µs/Div)

Fig. 68. FFT of Bearing current of IM in dBµA (500µs/Div)
Fig. 69. FFT of Bearing current of IM in dBµA (Expanded view, 500µs/Div)

Fig. 70. FFT of phase voltage in volts (200µs/Div)

Fig. 71. FFT of phase voltage in volts (Expanded view, 200µs/Div)

Fig. 72. FFT of phase voltage in dBµV (200µs/Div)

Fig. 73. FFT of phase voltage in dBµV (Expanded view, 200µs/Div)

Fig. 74. FFT of CM voltage in volts (200µs/Div)
Fig. 74. FFT of CM voltage in dBµV (200µs/Div)

Fig. 75. FFT of Bearing current of IM in amps (200µs/Div)

Fig. 76. FFT of Bearing current of IM in amps (Expanded view, 200µs/Div)

Fig. 77. FFT of Bearing current of IM in dBµA (200µs/Div)

Fig. 78. FFT of Bearing current of IM in dBµA (Expanded view, 200µs/Div)

Fig. 79. FFT of Phase voltage of IM in volts (100µs/Div)
Fig. 80. FFT of Phase voltage of IM in volts (Expanded view, 100µs/Div)

Fig. 81. FFT of Phase voltage of IM in dBµV (Expanded view, 100µs/Div)

Fig. 82. FFT of CM voltage in volts (100µs/Div)

Fig. 83. FFT of CM voltage in dBµV (100µs/Div)

Fig. 84. FFT of Bearing current in amps (100µs/Div)

Fig. 85. FFT of Bearing current in dB µA (100µs/Div)
APPENDIX-4

Assembler Code for 2-Level SVM for PIC 16F877

list p=16f877
#include <p16f877.inc>
__CONFIG (_CP_OFF & _WDT_OFF & _BODEN_OFF & _PWRTE_OFF & _XT_OSC)

ORG 0xf0
goto main

main
bcf STATUS,RP1
bsf STATUS,RP0
movlw 0x00
movwf TRISB

movlw 0x01
movwf TRISA

bcf STATUS,RP0

movlw 0x01
movwf 0x2a
movlw 0x03
movwf 0x2b
movlw 0x02
movwf 0x2c
movlw 0x06
movwf 0x2d
movlw 0x04
movwf 0x2e

movlw 0x05
movwf 0x2f

L1 movlw 0x03
movwf 0x4b
movlw 0x2a
movwf FSR
L2 movlw 0x02
movwf 0x4a
L3 movf INDF,W
movwf PORTB
incf FSR,1
movlw 0x0f
movwf 0x6b
movlw 0xd8
movwf 0x6a

call DELAY

decfsz 0x6a,1
goto L4

decfsz 0x6b,1
goto L3

goto L1

DELAY
L4 decfsz 0x6a,1
goto L4
decfsz 0x6b,1
goto L4
return
end
Micro-controller program for the generation of the gating pulses for 3-level NPC Inverter.

```c
#include <16F877.h>
#define adc=8
// #use delay(clock=11059200)
#use delay(clock=10000000)
#define a1_on output_high(pin_b7);
#define a1_off output_low (pin_b7);
#define b1_on output_high(pin_b5);
#define b1_off output_low (pin_b5);
#define c1_on output_high(pin_b3);
#define c1_off output_low (pin_b3);
#define a2_on output_high(pin_b6);
#define a2_off output_low (pin_b6);
#define b2_on output_high(pin_b4);
#define b2_off output_low (pin_b4);
#define c2_on output_high(pin_b2);
#define c2_off output_low (pin_b2);

void main()
{
    setup_adc_ports(NO_ANALOGS);
    setup_adc(ADC_OFF);
    setup_psp(PSP_DISABLED);
    setup_spi(FALSE);
    setup_counters(RTCC_INTERNAL,RTCC_DIV_1);
    setup_timer_1(T1_DISABLED);
    setup_timer_2(T2_DISABLED,0,1);
    output_b(0);
    repeat:
        a1_off; a2_on; b1_off; b2_off; c1_on; c2_on;
        delay_us(500);   //1
```
a1_on;
delay_us(2250);    //2
c1_off;
delay_us(2250);    //3
c2_off;
delay_us(4000);    //4
b2_on;
delay_us(500);    //5
b1_on;
delay_us(3000);    //6
a1_off;
delay_us(500);    //7
a2_off;
delay_us(3000);    //8
c2_on;
delay_us(500);    //9
c1_on;
delay_us(4000);    //10
b1_off;
delay_us(2250);    //11
b2_off;
delay_us(2250);    //12

goto repeat;
}
Micro-controller program for the generation of the gating pulses for 5-level NPC Inverter.

#include <16F877.h>
#include adc=8
// #use delay(clock=11059200)
use delay(clock=10000000)
#fuses NOWDT,XT, NOPUT, PROTECT, NOBROWNOUT, NOLVP, NOCPD, WRT, NODEBUG

#define a1_on output_high(pin_b7);
#define a1_off output_low (pin_b7);

#define a2_on output_high(pin_b6);
#define a2_off output_low (pin_b6);

#define a3_on output_high(pin_b5);
#define a3_off output_low (pin_b5);

#define a4_on output_high(pin_b4);
#define a4_off output_low (pin_b4);

#define b1_on output_high(pin_b3);
#define b1_off output_low (pin_b3);

#define b2_on output_high(pin_b2);
#define b2_off output_low (pin_b2);

#define b3_on output_high(pin_b1);
#define b3_off output_low (pin_b1);

#define b4_on output_high(pin_b0);
#define b4_off output_low (pin_b0);

#define c1_on output_high(pin_d7);
#define c1_off output_low (pin_d7);

#define c2_on output_high(pin_d6);
#define c2_off output_low (pin_d6);

#define c3_on output_high(pin_d5);
#define c3_off output_low (pin_d5);

#define c4_on output_high(pin_d4);
#define c4_off output_low (pin_d4);
#define d1_on output_high(pin_c7);
#define d1_off output_low (pin_c7);
#define d2_on output_high(pin_c6);
#define d2_off output_low (pin_c6);
#define d3_on output_high(pin_c5);
#define d3_off output_low (pin_c5);
#define d4_on output_high(pin_c4);
#define d4_off output_low (pin_c4);

void main()
{
  setup_adc_ports(NO_ANALOGS);
  setup_adc(ADC_OFF);
  setup_psp(PSP_DISABLED);
  setup_spi(FALSE);
  setup_counters(RTCC_INTERNAL,RTCC_DIV_1);
  setup_timer_1(T1_DISABLED);
  setup_timer_2(T2_DISABLED,0,1);
  output_b(0); output_c(0); output_d(0);

  repeat:
    a3_on; a4_on;
    b1_on; b2_on; b3_on; b4_on;
    delay_us(1000); //1
    a2_on;
    delay_us(1000); //2
    a1_on;
    delay_us(1000); //3
    b1_off;
    delay_us(1000); //4
    b2_off;
    delay_us(1000); //5
    b3_off;
    delay_us(1000); //6
    b4_off;
    delay_us(1000); //7
    c4_on;
}
delay_us(1000);      //8  
c3_on;              
delay_us(1000);      //9  
c2_on;              
delay_us(1000);      //10  
c1_on;              
delay_us(1000);      //11  
a1_off;             
delay_us(1000);      //12  
a2_off;             
delay_us(1000);      //13  
a3_off;             
delay_us(1000);      //14  
a4_off;             
delay_us(1000);      //15  
b4_on;              
delay_us(1000);      //16  
b3_on;              
delay_us(1000);      //17  
b2_on;              
delay_us(1000);      //18  
b1_on;              
delay_us(1000);      //19  
c1_off;             
delay_us(1000);      //20  
c2_off;             
delay_us(1000);      //21  
c3_off;             
delay_us(1000);      //22  
c4_off;             
delay_us(1000);      //23  
a4_on;              
delay_us(1000);      //24  
goto repeat;
**Explanation of CM equivalent circuit model and bearing model**

Fig. 1 shows a cross section of an IM and the different machine capacitances that represent the electrostatic coupling. $C_{sf}$ represents the stator winding to the frame capacitance, $C_{rf}$ represents the rotor to the frame capacitance and $C_{sr}$ represents the coupling mechanism for the shaft voltage. The motor electrostatic coupling can be modeled by an equivalent π network shown in Fig. 2. These capacitances can be calculated using standard geometric shapes. The bearing model, shown in Fig. 3, consists of a bearing resistance $R_b$ in series with parallel combination of the bearing oil film $C_b$ and a nonlinear impedance $Z_l$ which accounts for the charging and discharging of the shaft voltage.

The equivalent circuit of the adjustable drive system is shown in Fig. 4 in which the PWM inverter is modeled as a balanced three phase source with a common mode source from neutral to ground. The motor consists of two sets of balanced three phase winding coupled by an equivalent π network of machine capacitances in addition to the bearing model. For simulation and analysis of the common mode voltage and bearing currents, the common mode equivalent model of the drive system can be simplified as shown in Fig. 5. $R_0$ and $L_0$ represent the common mode impedance of the machine that equals one third of the stator resistance in series of one third of the stator leakage inductance.
Fig. 1. The electrostatic coupling effect of an induction machine

Fig. 2. The equivalent π network of machine capacitance

Fig. 3 The bearing model
Fig. 4. The inverter fed induction motor model

Fig. 5. The common mode equivalent circuit model
The simulation model of the power circuit diagram and the pulse generator for 5-level NPC inverter is as shown below.
**SVM Algorithm for n-level Inverter**

A simple SVM generation algorithm (steps) for any general n-Level inverter is given as below [69].

**Step 1.** Obtain the instantaneous values of three phase reference voltages $v_a$, $v_b$ and $v_c$.

**Step 2.** Resolve the reference space vector into the axes $j_a$, $j_b$ and $j_c$ using the following equations:

\[
v_{ja} = 0.866 (v_a - v_c) \quad \text{(1)}
\]

\[
v_{jb} = 0.866 (v_b - v_a) \quad \text{(2)}
\]

\[
v_{jc} = 0.866 (v_c - v_b) \quad \text{(3)}
\]

**Step 3.** Determine the layer of operation “m” using the equation

\[
m = 1 + \text{int} \left\{ \frac{v_{j_{\text{max}}}}{0.866V_{dc}/(n-1)} \right\} \quad \text{(4)}
\]

where m is the layer number.

**Step 4.** if (m>n-1)

Over modulation operation: $m = n - 1$, go to step 5).

else normal operation go to step 5).

**Step 5.** Identify the 60° region “S” of the multilevel inverter by comparing the amplitudes of the three phase reference voltages and determine the end vectors $(a_1,b_1,c_1)$ and $(a_2,b_2,c_2)$ in the inner side of the layer 2. Let the vectors on the inner side of layer 2 for any 60° region be $(a_1,b_1,c_1)$ and $(a_2,b_2,c_2)$ and the end vectors on the inner side of the layer $m$ be $(a_m,b_m,c_m)$ and $(a_{m2},b_{m2},c_{m2})$ then, the end vectors on the inner side of layer $m$ can be generated as

\[
(a_{m1},b_{m1},c_{m1}) = (m-1) (a_1,b_1,c_1) \quad \text{(5)}
\]

\[
(a_{m2},b_{m2},c_{m2}) = (m-1) (a_2,b_2,c_2) \quad \text{(6)}
\]

**Step 6.** Calculate the first end vector $(a_{m1},b_{m1},c_{m1})$ of the inner side of the layer $m$ using equation (5).

**Step 7.** Find the difference vector $\Delta$ as the difference of the end vectors obtained in step 5. \[\Delta = (a_2,b_2,c_2) - (a_1,b_1,c_1) \quad \text{(7)}\]

**Step 8.** Starting from the first end vector, generate other vectors in the inner side of layer $m$ by adding the difference vector repeatedly for $m-1$ times to get the candidate vector.

**Step 9.** Choose the vector which is closest to reference space vector as the center of the sub hexagon $(a,c,b,c)$ by calculating the distance term $d$ as given in equation 7.

\[
d_i = |v_a - a_{cv}| + |v_\beta - \beta_{cv}| \quad \text{(8)}
\]
where \((v_a, v_\beta)\) and \((a_{cv}, \beta_{cv})\) are the co ordinates of the reference space vector and co ordinate vector respectively. The candidate vector with the smallest distance term is the vector closest to the reference space vector and hence taken as the center of sub hexagon.

**Step 10.** Map the reference space vector to the inner sub hexagon and calculate the three instantaneous phase reference voltages of the mapped reference space vector by equation 8.

\[
v_a^1 = v_a - a_c, \quad v_\beta^1 = v_\beta - \beta_c \quad \text{------------------------(8)}
\]

**Step 11.** Generate the two level switching vectors and the optimum switching sequence for the mapped reference space vector with the 2 level SVM method.

**Step 12.** Add the center of the sub hexagon \((a_c, b_c, c_c)\) obtained in step 9 to the 2-level vectors to generate the switching vectors and optimum sequence for the multilevel inverter

\[
(a_m, b_m, c_m) = (a_0, b_0, c_0) + (a_c, b_c, c_c) \quad \text{--------- (9)}
\]

---

**THD\(_v\) Calculation.**

- THD\(_v\) is defined for voltage signal as follows:

\[
THD_v = \sqrt{\sum_{k=2}^{\infty} \frac{V_k^2}{V_1}}
\]

Where “\(h\)” is an integer and “\(V_1\)” is the fundamental frequency voltage component.

This means that the ratio between RMS values of signals including harmonics and signals considering only the fundamental frequency define the total harmonic distortion.