Appendix A SHE STAIRCASE ANGLE COMPUTATION

A MATLAB script is used to compute the angles, $\alpha_1 - \alpha_4$, required for SHE-4H4 control. The iterative Newton-Raphson method is used to solve the following set of simultaneous equations

$$\cos(\alpha_1)+\cos(\alpha_2)-\cos(\alpha_3)+\cos(\alpha_4)=\frac{\pi m_a}{2} \quad \ldots (3.2.3)$$

$$\cos(5\alpha_1)+\cos(5\alpha_2)-\cos(5\alpha_3)+\cos(5\alpha_4)=0 \quad \ldots (3.2.4)$$

$$\cos(7\alpha_1)+\cos(7\alpha_2)-\cos(7\alpha_3)+\cos(7\alpha_4)=0 \quad \ldots (3.2.5)$$

$$\cos(11\alpha_1)+\cos(11\alpha_2)-\cos(11\alpha_3)+\cos(11\alpha_4)=0 \quad \ldots (3.2.6)$$

The complete listing of the m-file function is as follows:

```
% she.m
% Newton-Raphson solver for four angle SHE control
% ma is the modulation amplitude
% xn is the number of inverter cells
% bn is b coefficient index vector
% bvalue is b coefficient value array
% function returns first 21 b coefficients
% 4 angle search

function vector=she(ma)
xn=4;
bn=[1 5 7 11];
bvalue=[1 0 0 0];
n=10;               % first 20 coefficients
nTrial=20;          % number of trials

for i=1:xn
    bnvalue(i)=2*ma*bvalue(i);     % scale bn target values
end

% initial seed values to aid convergence
alpha=[0.35 1.1 1.5 1.35];

for T=1:nTrial
```

```
    for i=1:n
        index=2*i-1;
        % set even number b coefficient to zero
        b(index+1)=0.0;
        % sum components
        b(index)=cos(index*alpha(1))
        b(index)=b(index)+cos(index*alpha(2));
        b(index)=b(index)+cos(index*alpha(3));
        b(index)=b(index)-cos(index*alpha(4));
        % scale
        b(index) = b(index)*4/(index*pi);
    end

    % matrix of partial derivatives A(alpha) and negative of
    % function B(alpha)
    for j=1:xn
        B(j)=-b(bn(j)) + bnvalue(j);
        A(j,1)=-4/pi*(sin(bn(j)*alpha(1)));
        A(j,2)=-4/pi*(sin(bn(j)*alpha(2)));
        A(j,3)=-4/pi*(sin(bn(j)*alpha(3)));
        A(j,4)=4/pi*(sin(bn(j)*alpha(3)));
    end

    deltaAlpha=A\B';           % uses LU decomposition
    for j=1:xn
    alpha(j) =alpha(j)+deltaAlpha(j);
    end
end

vector=alpha; % return complete set of firing angles
```

Appendix B PUBLISHED PAPER BIBLIOGRAPHY

[B.1] **Title:** Modelling and control of a flying-capacitor inverter

Authors: Watkins, S.J., and Zhang, L.

Source: Proceedings of EPE '01, 9th European Conference on Power Electronics and Applications, Graz, Austria, 27 - 29 August, 2001, CDROM Paper No. PP00439.

Abstract: This paper presents the results of an investigation into the variation in the output voltage quality of a flying-capacitor inverter under staircase angle control. The trade-offs between capacitor size, power device voltage rating and output voltage quality are assessed through simulation. A general mathematical model for an N-level inverter is used for circuit operation analysis and its results are compared with those from a Simulink® circuit simulation. The computer model allows a thorough investigation of all possible switching pattern permutations that produce the desired sinusoidal output and maintain steady state capacitor voltage balancing. Results show that the total harmonic distortion in a sinusoidal synthesised output can be minimised by the correct selection of the switching mode sequence.

[B.2] **Title:** Influence of multilevel sinusoidal PWM schemes on the performance of a flying-capacitor inverter

Authors: Watkins, S.J. and Zhang, L.

Source: Proceedings of PEMD '02, the 1st International Conference on Power Electronics Machines and Drives (IEE Conference Publication No. 487), Bath, UK, 16 - 18 April, 2002, pp 92 - 97.

Abstract: Multilevel inverters, including the flying-capacitor topology require more complex control due to the additional flexibility offered by the multiple output voltage levels. One such control method is based on the conventional sinusoidal pulse width modulation (SPWM) scheme and uses multiple triangular carriers. There are a number of SPWM variants that achieve the desired inverter control. This paper presents the results of an investigation into these different schemes and their influence on the power quality and efficiency of a flying-capacitor inverter.

[B.3] **Title:** Multilevel asymmetric power converters for switched reluctance machines

Authors: Watkins, S.J., Čorda, J. and Zhang, L.

Source: Proceedings of PEMD '02, the 1st International Conference on Power Electronics Machines and Drives (IEE Conference Publication No. 487), Bath, UK, 16 - 18 April, 2002, pp 195 - 200.

Abstract: This paper presents a new family of multilevel asymmetric power converters which are suitable for unipolar current loads such as a switched reluctance motor drive. The fundamental operation of each topology is reviewed and some simulation results are presented showing the potential system performance improvements that can be realised by operating with intermediary voltages rather than the full dc-link.

[B.4] **Title:** Analysis and control of a multi-level flying capacitor inverter

Authors: Zhang, L., Watkins, S.J. and Shepherd, W.

Source: Proceedings of CIEP '02, 8th IEEE International Power Electronics Congress, Guadalajara, Mexico, 20 – 24 October, 2002, pp. 66 – 71.

Abstract: The paper presents the results of a study into the optimal switch mode sequence for a multi-level flying capacitor inverter to synthesis a sinewave voltage under staircase angle control. It is shown that a properly selected sequence will yield the voltage and loss balances in capacitor voltages and switching devices respectively and minimize the load voltage THD values. A general mathematical model for an N-level inverter is presented which can be conveniently applied for computer simulation of any operating mode.

[B.5] **Title:** An SR drive for a multi-megawatt high-speed application

Authors: Watkins, S.J. and Čorda, J.

Source: Proceedings of EPE '03, 10th European Conference on Power Electronics and Applications, Toulouse, France, 2 - 4 September, 2003, CD-ROM Paper No. 0071.

Abstract: The paper gives an insight into the main features of an SR drive system from the perspective of a multi-megawatt drive

application where the rated speed is typically above ten thousand rev/min and the operating voltage is in the range of several kV. The power electronic converter is based on a topology, which allows the application of multiple voltage levels to the machine's phase windings, while utilising lower voltage, fast switching IGBTs. The system's performance is illustrated by means of computer simulation which includes modelling of the electronics conduction and switching losses together with the copper and iron-loss in the machine.

[B.6] **Title:** Multilevel space vector PWM control schemes for a flying-capacitor inverter

Authors: Watkins, S.J., and Zhang, L.

Source: Proceedings of PEMD '04, the 2nd International Conference on Power Electronics, Machines and Drives (IEE Conference Publication No. 498), Edinburgh, UK, 31 March - 2 April, 2004, Vol. 1, pp. 12 – 17.

Abstract: The paper presents three different computational schemes for achieving space vector pulse width modulation, in the control of a multilevel flying capacitor inverter. Each scheme uses the same method of achieving cell-capacitor voltage balancing. Results of realistic simulations are used to compare and contrast these approaches. The timing control of the inverter switches and output performance of each method are presented and the most suitable one is highlighted.