

Supplementary File

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1 Supplementary tables

Table S1: Simulated current values and absolute error values of AMLCSA for the single diode model.

| Item | $V_L(V)$ | $I_L(A)$ | I_L calculated (A) | IAE |
|------------|----------|----------|--------------------------|------------|
| 1 | -0.2057 | 0.7640 | 0.76408764 | 0.00008764 |
| 2 | -0.1291 | 0.7620 | 0.76266264 | 0.00066264 |
| 3 | -0.0588 | 0.7605 | 0.76135473 | 0.00085473 |
| 4 | 0.0057 | 0.7605 | 0.76015423 | 0.00034577 |
| 5 | 0.0646 | 0.7600 | 0.75905585 | 0.00094415 |
| 6 | 0.1185 | 0.7590 | 0.75804301 | 0.00095699 |
| 7 | 0.1678 | 0.7570 | 0.75709159 | 0.00009159 |
| 8 | 0.2132 | 0.7570 | 0.75614207 | 0.00085793 |
| 9 | 0.2545 | 0.7555 | 0.75508732 | 0.00041268 |
| 10 | 0.2924 | 0.7540 | 0.75366447 | 0.00033553 |
| 11 | 0.3269 | 0.7505 | 0.75138806 | 0.00088806 |
| 12 | 0.3585 | 0.7465 | 0.74734834 | 0.00084834 |
| 13 | 0.3873 | 0.7385 | 0.74009688 | 0.00159688 |
| 14 | 0.4137 | 0.7280 | 0.72739678 | 0.00060322 |
| 15 | 0.4373 | 0.7065 | 0.70695327 | 0.00045327 |
| 16 | 0.4590 | 0.6755 | 0.67529489 | 0.00020511 |
| 17 | 0.4784 | 0.6320 | 0.63088431 | 0.00111569 |
| 18 | 0.4960 | 0.5730 | 0.57208207 | 0.00091793 |
| 19 | 0.5119 | 0.4990 | 0.49949164 | 0.00049164 |
| 20 | 0.5265 | 0.4130 | 0.41349356 | 0.00049356 |
| 21 | 0.5398 | 0.3165 | 0.31721950 | 0.00071950 |
| 22 | 0.5521 | 0.2120 | 0.21210317 | 0.00010317 |
| 23 | 0.5633 | 0.1035 | 0.10272135 | 0.00077865 |
| 24 | 0.5736 | -0.0100 | -0.00924885 | 0.00075115 |
| 25 | 0.5833 | -0.1230 | -0.12438136 | 0.00138136 |
| 26 | 0.5900 | -0.2100 | -0.20919308 | 0.00080692 |
| Sum of IAE | | | | 0.01770412 |

Table S2: Simulated current values and absolute error values of AMLCSA for the double diode model.

| Item | $V_L(V)$ | $I_L(A)$ | I_L calculated (A) | IAE |
|------------|----------|----------|----------------------|------------|
| 1 | -0.2057 | 0.7640 | 0.76398339 | 0.00001661 |
| 2 | -0.1291 | 0.7620 | 0.76260368 | 0.00060368 |
| 3 | -0.0588 | 0.7605 | 0.76133714 | 0.00083714 |
| 4 | 0.0057 | 0.7605 | 0.76017401 | 0.00032599 |
| 5 | 0.0646 | 0.7600 | 0.75910829 | 0.00089171 |
| 6 | 0.1185 | 0.7590 | 0.75812204 | 0.00087796 |
| 7 | 0.1678 | 0.7570 | 0.75718851 | 0.00018851 |
| 8 | 0.2132 | 0.7570 | 0.75624427 | 0.00075573 |
| 9 | 0.2545 | 0.7555 | 0.75517770 | 0.00032230 |
| 10 | 0.2924 | 0.7540 | 0.75372289 | 0.00027711 |
| 11 | 0.3269 | 0.7505 | 0.75139613 | 0.00089613 |
| 12 | 0.3585 | 0.7465 | 0.74729617 | 0.00079617 |
| 13 | 0.3873 | 0.7385 | 0.73999137 | 0.00149137 |
| 14 | 0.4137 | 0.7280 | 0.72726486 | 0.00073514 |
| 15 | 0.4373 | 0.7065 | 0.70683578 | 0.00033578 |
| 16 | 0.4590 | 0.6755 | 0.67523009 | 0.00026991 |
| 17 | 0.4784 | 0.6320 | 0.63088762 | 0.00111238 |
| 18 | 0.4960 | 0.5730 | 0.57214027 | 0.00085973 |
| 19 | 0.5119 | 0.4990 | 0.49957060 | 0.00057060 |
| 20 | 0.5265 | 0.4130 | 0.41355634 | 0.00055634 |
| 21 | 0.5398 | 0.3165 | 0.31724208 | 0.00074208 |
| 22 | 0.5521 | 0.2120 | 0.21208148 | 0.00008148 |
| 23 | 0.5633 | 0.1035 | 0.10267156 | 0.00082844 |
| 24 | 0.5736 | -0.0100 | -0.00929723 | 0.00070277 |
| 25 | 0.5833 | -0.1230 | -0.12439037 | 0.00139037 |
| 26 | 0.5900 | -0.2100 | -0.20914690 | 0.00085310 |
| Sum of IAE | | | | 0.01731851 |

Table S3: Simulated current values and absolute error values of AMLCSA for the Photowatt-PWP201 module.

| Item | $V_L(V)$ | $I_L(A)$ | I_L calculated (A) | IAE |
|------------|----------|----------|----------------------|------------|
| 1 | 0.1248 | 1.0315 | 1.02912209 | 0.00237791 |
| 2 | 1.8093 | 1.0300 | 1.02738435 | 0.00261565 |
| 3 | 3.3511 | 1.0260 | 1.02574214 | 0.00025786 |
| 4 | 4.7622 | 1.0220 | 1.02410399 | 0.00210399 |
| 5 | 6.0538 | 1.0180 | 1.02228341 | 0.00428341 |
| 6 | 7.2364 | 1.0155 | 1.01991740 | 0.00441740 |
| 7 | 8.3189 | 1.0140 | 1.01635081 | 0.00235081 |
| 8 | 9.3097 | 1.0100 | 1.01049143 | 0.00049143 |
| 9 | 10.2163 | 1.0035 | 1.00067876 | 0.00282124 |
| 10 | 11.0449 | 0.9880 | 0.98465335 | 0.00334665 |
| 11 | 11.8018 | 0.9630 | 0.95969741 | 0.00330259 |
| 12 | 12.4929 | 0.9255 | 0.92304875 | 0.00245125 |
| 13 | 13.1231 | 0.8725 | 0.87258816 | 0.00008816 |
| 14 | 13.6983 | 0.8075 | 0.80731012 | 0.00018988 |
| 15 | 14.2221 | 0.7265 | 0.72795782 | 0.00145782 |
| 16 | 14.6995 | 0.6345 | 0.63646618 | 0.00196618 |
| 17 | 15.1346 | 0.5345 | 0.53569607 | 0.00119607 |
| 18 | 15.5311 | 0.4275 | 0.42881615 | 0.00131615 |
| 19 | 15.8929 | 0.3185 | 0.31866866 | 0.00016866 |
| 20 | 16.2229 | 0.2085 | 0.20785711 | 0.00064289 |
| 21 | 16.5241 | 0.1010 | 0.09835421 | 0.00264579 |
| 22 | 16.7987 | -0.0080 | -0.00816934 | 0.00016934 |
| 23 | 17.0499 | -0.1110 | -0.11096846 | 0.00003154 |
| 24 | 17.2793 | -0.2090 | -0.20911762 | 0.00011762 |
| 25 | 17.4885 | -0.3030 | -0.30202238 | 0.00097762 |
| Sum of IAE | | | | 0.04178790 |

Table S4: Simulated current values and absolute error values of AMLCSA for the STM6-40/36 module.

| Item | $V_L(V)$ | $I_L(A)$ | I_L calculated (A) | IAE |
|------------|----------|----------|----------------------|------------|
| 1 | 0.0000 | 1.6630 | 1.66345813 | 0.00045813 |
| 2 | 0.1180 | 1.6630 | 1.66325224 | 0.00025224 |
| 3 | 2.2370 | 1.6610 | 1.65955120 | 0.00144880 |
| 4 | 5.4340 | 1.6530 | 1.65391444 | 0.00091444 |
| 5 | 7.2600 | 1.6500 | 1.65056575 | 0.00056575 |
| 6 | 9.6800 | 1.6450 | 1.64543044 | 0.00043044 |
| 7 | 11.5900 | 1.6400 | 1.63923405 | 0.00076595 |
| 8 | 12.6000 | 1.6360 | 1.63371510 | 0.00228490 |
| 9 | 13.3700 | 1.6290 | 1.62728848 | 0.00171152 |
| 10 | 14.0900 | 1.6190 | 1.61831518 | 0.00068482 |
| 11 | 14.8800 | 1.5970 | 1.60306738 | 0.00606738 |
| 12 | 15.5900 | 1.5810 | 1.58158500 | 0.00058500 |
| 13 | 16.4000 | 1.5420 | 1.54232745 | 0.00032745 |
| 14 | 16.7100 | 1.5240 | 1.52122497 | 0.00277503 |
| 15 | 16.9800 | 1.5000 | 1.49920572 | 0.00079428 |
| 16 | 17.1300 | 1.4850 | 1.48527115 | 0.00027115 |
| 17 | 17.3200 | 1.4650 | 1.46564321 | 0.00064321 |
| 18 | 17.9100 | 1.3880 | 1.38759934 | 0.00040066 |
| 19 | 19.0800 | 1.1180 | 1.11837210 | 0.00037210 |
| 20 | 21.0200 | 0.0000 | -0.00002131 | 0.00002131 |
| Sum of IAE | | | | 0.02177457 |

Table S5: Simulated current values and absolute error values of AMLCSA for the STP6-120/36 module.

| Item | $V_L(V)$ | $I_L(A)$ | I_L calculated (A) | IAE |
|------------|----------|----------|----------------------|------------|
| 1 | 19.2100 | 0.0000 | 0.00116434 | 0.00116434 |
| 2 | 17.6500 | 3.8300 | 3.83228231 | 0.00228231 |
| 3 | 17.4100 | 4.2900 | 4.27392907 | 0.01607093 |
| 4 | 17.2500 | 4.5600 | 4.54628941 | 0.01371059 |
| 5 | 17.1000 | 4.7900 | 4.78583301 | 0.00416699 |
| 6 | 16.9000 | 5.0700 | 5.08193389 | 0.01193389 |
| 7 | 16.7600 | 5.2700 | 5.27376516 | 0.00376516 |
| 8 | 16.3400 | 5.7500 | 5.77681380 | 0.02681380 |
| 9 | 16.0800 | 6.0000 | 6.03749239 | 0.03749239 |
| 10 | 15.7100 | 6.3600 | 6.34872743 | 0.01127257 |
| 11 | 15.3900 | 6.5800 | 6.56792937 | 0.01207063 |
| 12 | 14.9300 | 6.8300 | 6.81486011 | 0.01513989 |
| 13 | 14.5800 | 6.9700 | 6.95844905 | 0.01155095 |
| 14 | 14.1700 | 7.1000 | 7.08813731 | 0.01186269 |
| 15 | 13.5900 | 7.2300 | 7.21776060 | 0.01223940 |
| 16 | 13.1600 | 7.2900 | 7.28412985 | 0.00587015 |
| 17 | 12.7400 | 7.3400 | 7.33148307 | 0.00851693 |
| 18 | 12.3600 | 7.3700 | 7.36326479 | 0.00673521 |
| 19 | 11.8100 | 7.3800 | 7.39587314 | 0.01587314 |
| 20 | 11.1700 | 7.4100 | 7.42026500 | 0.01026500 |
| 21 | 10.3200 | 7.4400 | 7.43909223 | 0.00090777 |
| 22 | 9.7400 | 7.4200 | 7.44671497 | 0.02671497 |
| 23 | 9.0600 | 7.4500 | 7.45253755 | 0.00253755 |
| 24 | 0.0000 | 7.4800 | 7.47098129 | 0.00901871 |
| Sum of IAE | | | | 0.27797597 |

2 Influence of parameter sp values on the AMLCSA algorithm

In AMLCSA, the selection probability sp is used to select between two updating formulas in the adaptive multiple learning strategy. In the AML strategy, it is assumed that most individuals acquire new knowledge through various channels. Therefore, the selection probability should be set greater than 0.5. Table S6 presents the statistical results of AMLCSA with different sp values for the PV module models. The best results are obtained for both models when $sp = 0.6$. Thus, this parameter is set to 0.6 in the present study.

Table S6: Statistical results of AMLCSO with different sp values for two PV module.

| Model | Parameter | RMSE | | | | Sig |
|-------------|------------|-------------------|-------------------|-------------------|-------------------|-----|
| | | Best | Worst | Mean | Std | |
| STM6-40/36 | $sp = 0.6$ | 1.7298E-03 | 1.7298E-03 | 1.7298E-03 | 3.8209E-16 | |
| | $sp = 0.7$ | 1.7298E-03 | 1.7298E-03 | 1.7298E-03 | 4.4406E-13 | + |
| | $sp = 0.8$ | 1.7298E-03 | 1.7298E-03 | 1.7298E-03 | 3.8395E-10 | + |
| | $sp = 0.9$ | 1.7298E-03 | 3.2818E-03 | 2.0101E-03 | 4.5748E-04 | + |
| STP6-120/36 | $sp = 0.6$ | 1.6601E-02 | 1.6601E-02 | 1.6601E-02 | 6.6536E-13 | |
| | $sp = 0.7$ | 1.6601E-02 | 1.6603E-02 | 1.6601E-02 | 3.5402E-07 | + |
| | $sp = 0.8$ | 1.6601E-02 | 1.7016E-02 | 1.6635E-02 | 8.7940E-05 | + |
| | $sp = 0.9$ | 1.6601E-02 | 2.8057E-02 | 1.7151E-02 | 2.1271E-03 | + |

The best results are highlighted in bold font.