A Review of Solar Energy Forecasting Requirements, and a Proposed Approach for the Development of an Australian Solar Energy Forecasting System (ASEFS)

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Summary

Electricity supply systems attempt to balance supply and demand requirements at time scales from seconds to years. Scheduling of generation assets is made against forecast demand. Increasing levels of non-forecast intermittent renewable generation increases the uncertainty in demand forecasts leading to inefficient generator scheduling and potentially resulting in system contingency services failing to cope. The Australian Energy Market Operator (AEMO) has been running an Australian Wind Energy Forecasting System (AWEFS) successfully since 2008 to incorporate wind power generation into the National Electricity Market (NEM). In light of the proposed construction of two large Solar Flagships power stations and the rapid increase in smaller distributed PV systems, and an expectation that solar generation capacity in the NEM will continue to increase over the coming years AEMO has identified a need for solar energy production to be forecast in the NEM. The current AWEFS system is modular and can be extended to incorporate solar energy forecasting.

This report has been prepared as the final output of work undertaken by Dr. Peter Coppin of the Commonwealth Scientific and Industrial Research Organisation (CSIRO), to conduct a high-level review of solar energy forecasting (SEF) and key related activities in Australia, identify potential gaps/needs in this area, and provide recommendations for solar energy forecasting research and development priorities, including the development of a high level scope for an Australian Solar Energy Forecasting System (ASEFS) to be operated by AEMO.

This work and its outputs were also intended to provide a context for stakeholder consultations, as well as ASI Board consideration around potential future funding in the area. Inputs to this report have included: responses to an ASI call-for-comments on the proposed ASEFS; attendee feedback during the ASI-supported solar forecasting workshop in November 2011; and various discussions with staff from AEMO and ASI, and other SEF stakeholders.

The state of SEF development is such that only a basic set of techniques, mostly developed overseas, are ready for implementation in an operational ASEFS. Further R&D is required on a series of techniques which will be necessary to satisfy the full range of time-scales required by AEMO. A three-phase approach to developing ASEFS is recommended in this report where Phase I implements a fully operational but very basic ASEFS incorporating proven SEF techniques covering the required AEMO forecasting time horizons from 5 minutes to 2 years, and develops existing but not yet fully-proven techniques, Phase II implements these latter techniques and develops more advanced techniques to be implemented in Phase III (see Figure 1 below).

Much of the R&D required would need to be undertaken in consultation with overseas institutions which have developed a number of key techniques, but with rigorous local testing and validation to ensure their applicability in the Australian context and for the ASEFS system. There is plenty of scope for local R&D as many aspects of SEF remain to be developed worldwide. It is also expected that the skills and knowledge gained through the development of an ASEFS would be applicable to a number of related areas such as scheduling of electrical storage systems and the operation of smart grid systems.

A detailed listing of the proposed activities involved in the development of an ASEFS, including the R&D activities required, is contained in Section 7 of this document, along with a proposed implementation timeframe. A brief outline of the key components of the proposed ASEFS development process is provided below.

To provide robust operational solar forecasting capabilities for Australia, and key underpinning science, the recommended key components in the proposed ASEFS development process are:

Phase I – System Design - Benchmarking – Implementation of baseline forecasting – 18 months

1. Review of existing and proposed overseas approaches to integrating solar energy forecasting into electricity supply systems
2. Define specification and determine changes to AWEFS architecture to implement Phase I
3. Develop essential background validation; define data sets and metrics
4. Implement architectural changes to AWEFS
5. Develop initial base-line radiation-to-power conversion models
6. Tender and install Phase I power forecasting capability, PV, CST, distributed PV at all time scales (note that solutions need to be run inside the current AWEFS system)
7. Determine range of inputs to be catered for in Phase II – outline implications for ASEFS architecture
8. R&D for Phase II implementation – emphasis on 0-24 hour ahead prediction for single-site, distributed PV, and intermittency

Phase II – Implementation of upgraded 0-24 hour prediction, improved distributed PV, intermittency and validation studies – 18 months to Year 3

1. Essential validation, establish base-line ASEFS forecasting accuracy and uncertainties
2. Implement architectural changes to ASEFS for Phase II
3. Develop improved radiation-to-power conversion models
4. Detailed evaluation of candidates for Phase III power forecasting capability upgrade against cost-benefit
5. R&D for Phase III implementation

Phase III - Extended Validation – Advanced forecasting schemes – Years 3-5

1. Implement forecasting upgrade candidates developed in Phase II when proven
2. Essential validation of ASEFS with forecasting upgrades
3. Further R&D based on experience from operational system

Estimates of costs, and identification of specific sources of funding, for the ASEFS/SEF development activities proposed herein have not been made in this report, and are to be determined separately.

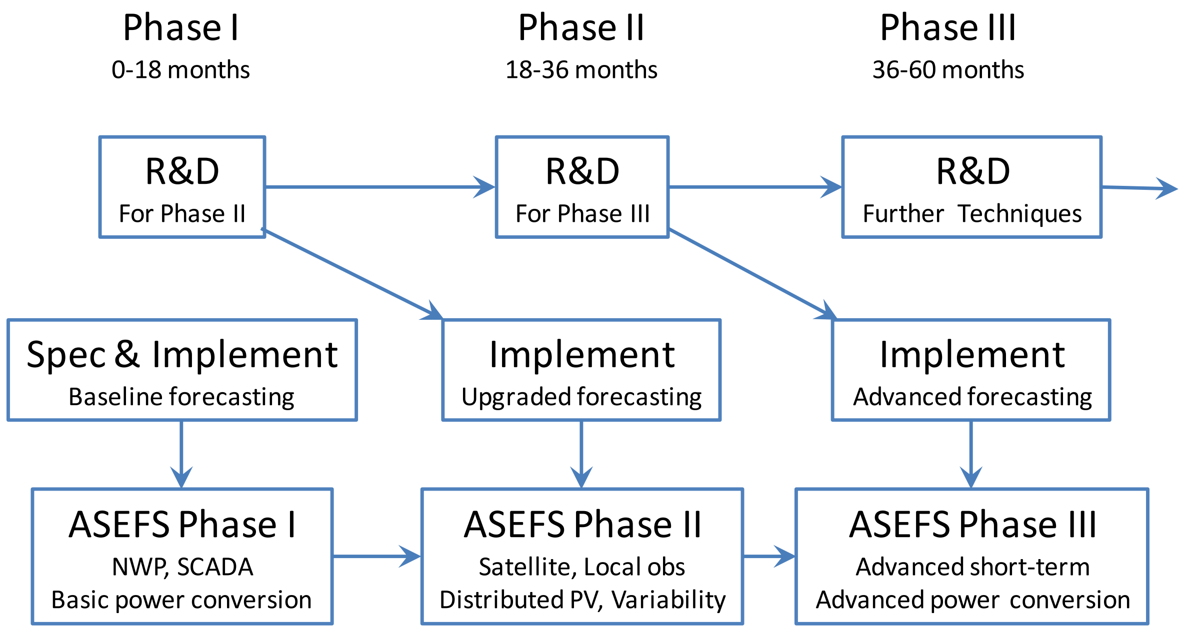

Figure 1 Implementation flow for ASEFS

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1. The need for solar energy forecasting

Electricity supply systems attempt to balance supply and demand requirements at time scales from seconds to years. Scheduling of generation assets is made against forecast demand. Increasing levels of non-forecast intermittent renewable generation increases the uncertainty in demand forecasts leading to inefficient generator scheduling and potentially resulting in system contingency services failing to cope. All power systems with significant amounts of wind power now employ wind forecasting to help manage these problems. In Australia AEMO utilises a state-of-the-art centralised wind energy forecasting system (the Australian Wind Energy Forecasting System - AWEFS) which provides forecasts of wind energy production for all wind farms greater than 30MW nameplate capacity over timescales from 5 minutes to 2 years using a variety of forecasting techniques. The system, operational at AEMO since November 2008, is widely regarded as the most capable and accurate system of its type in the world. The AWEFS architecture, being modular and extensible, is able to provide public researcher access for continuous improvement. This system has proved highly effective, allowing the wind energy production to be factored in to system security and scheduling of conventional plant allowing efficient energy market operation and benefitting transmission planning. Experience with the system and confidence in its accuracy also allows wind plant owners to more actively participate in the market to extract extra value.

The current AWEFS system uses 3 weather forecast (Numerical Weather Prediction - NWP) feeds from Australia, the USA and Europe to drive the shorter-term forecasts. It employs up to 6 different wind power forecasting techniques in a modular arrangement with a decision engine to determine the most suitable combination for current conditions based on historical performance. These modules have well-established performance capabilities and most importantly, defined uncertainties.

Solar generating capacity in the National Electricity Market is rapidly reaching a stage where forecasting will be needed, particularly with the recent proliferation of grid-connected roof-top PV, which as of November 2011 is estimated to exceed 1,000MW installed capacity, the impending construction of 2 large Solar Flagship power stations of 150MW and 250MW capacity and other MW-scale plants. The ASEFS proposal is to utilise the modular architecture of the AWEFS system to include solar generators, covering the same time-scales and creating an "Australian Solar Energy Forecasting System" – ASEFS.

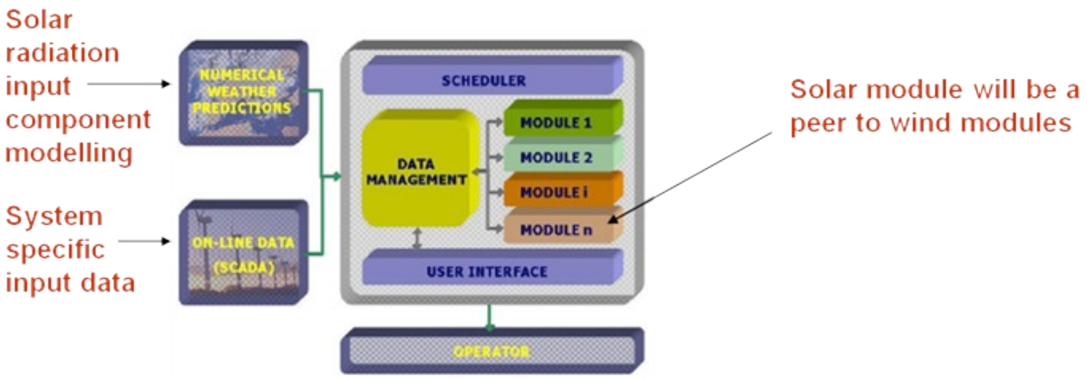

Figure 2 Proposed Australian Solar Energy Forecasting System based on the AWEFS system

The factors influencing solar power generation are quite different to those influencing wind power generation, for example scattered cloud can produce much more rapid swings in solar power than those experienced in wind power. The development of solar forecasting techniques requires a detailed knowledge of the relevant weather and climate processes. High quality solar radiations observations also play a vital role in advancing this knowledge.

One important feature of the proposed ASEFS system is the need to convert solar radiation forecasts into energy production forecasts. Machine learning techniques are commonly used to convert the radiation inputs into power production based on theoretical conversion models and corrected with measured production data. These techniques are reasonably straightforward for solar PV, but more complex models (or alternative approaches) are likely to be required for concentrating solar-thermal (CST) generation systems which can involve proprietary conversion processes and discretionary co-firing with gas.

It should be noted that "resource forecasting" or "resource prediction" is often directly confused with this energy production forecasting. Resource forecasting uses high-quality historical measured radiation data to calculate the likely energy yield from a planned power station over many years (ideally over the power station's lifetime) – producing an estimate or a "forecast" of the potential future energy yield as required for financing and permitting. An ASEFS system would focus on turning a combination of current observations and weather forecasts into energy production forecasts for the immediate future (e.g. minutes to days in advance). The overlap occurs when energy production forecasts are also required out to 2 years, as required by AEMO. In order to extend the forecast horizon beyond the 7-day weather forecast horizon a combination of historical data statistics and seasonal projections can be used to form a picture of likely future production.

It should also be noted that there are a large number of potential clients for the forecasts generated by an ASEFS system and the data sets gathered in the forecasting process. These include individual solar generators whose installed capacity falls below the 30MW AEMO threshold of interest. A number of related applications have demonstrated that forecasting can greatly enhance their effectiveness. These include – electrical storage systems for smoothing and energy time-shifting, and distribution-level smart grid systems.

2. The current status of SEF internationally

Solar forecasting is at a much earlier stage in its development than wind forecasting. The basic solar forecasting techniques have been established for some time in a number of research institutions such as University of Albany in New York State, NREL, University of California, San Diego, the Danish Technical University, the German Aerospace Agency and University of Oldenburg, Germany. A recent state-of-the-art review by the University of California[1] concluded that although forecasting techniques existed for each timeframe, much needed to be done to improve and validate these forecasts against observations, a necessary step to producing reliable operational systems with well understood uncertainties under all conditions. Research is also being undertaken into the issue of forecasting distributed PV generation at a number of institutions. In jurisdictions with high solar power penetration (Germany, Spain, USA) basic forecasting is already being utilised. For example in Germany a system from Meteocontrol is being used by all four German transmission network utilities[2]. A detailed review of the current solar forecasting techniques which are being deployed by utilities is planned in the first phase of the ASEFS development.

The University of California review found that at very short-timescales (<1hr) statistical methods (auto-regressive persistence –based methods) using power plant output data perform best combined with now-casting using on-site radiation and/or ground-based cloud imaging data. At medium time-scales (up to several hours) satellite observations combined with NWP-based radiation forecasts seem most effective. At times-scales from hours up to several days NWP forecasts are the best option, even though skill degrades considerably beyond a few days. It should also be noted that in an operational system it is normal to blend smoothly between the techniques used at the various timeframes. Beyond the seven-day weather forecasting timeframe statistical analysis of historic data should be used, with uncertainties based on inter-annual variability statistics.

There is a view that NWP-based radiation forecasts are not yet accurate enough for solar energy applications with a recent comparison indicating a typical 1 day-ahead error of over 30% for global irradiance (RMS error)[3], although this is likely to improve markedly through R&D in the near future. Of particular concern is the ability to forecast the direct beam

[1] Keissel, J (2010), California Renewable Energy Forecasting, Resource Data and Mapping, Appendix A, Current State of the Art in Solar Forecasting, University of California, Contract Number: 500-99-013

[2] http://www.meteocontrol.com/energy-weather-services/prognosis-services/solar-power-forecasts/

[3] Perez, R., M. Beauharnois, K. Hemker, Jr., S. Kivalov, E. Lorenz, S. Pelland, J. Schlemmer, G. Van Knowe, (2011): Evaluation of Numerical Weather Prediction Solar Irradiance Forecasts in the US, Proc. ASES National Conference, Raleigh, NC

component of the radiation (direct normal incident - DNI) which is important for concentrating solar power plants. To improve DNI forecasts, the prediction of cloud-type and the quantity of aerosols will need more research. The ECMWF[4] global model is generally regarded as the most accurate model for solar radiation forecasts but this fact remains to be tested in Australia.

There are a number of short-term solar forecasting schemes which make use of satellite imagery to detect cloud movements and evolution. However some of these use frequent imagery (10-15mins) available in the USA and Europe. Current imagery updates in Australia are only hourly, hence not particularly appropriate for operational solar power forecasts. A new Japanese satellite is planned for launch in 2014 which will provide higher resolution imagery at shorter intervals (10-minutes), and will be an important input into an ASEFS.

There are a number of commercial solar-forecasting services – but nowhere near the number or sophistication of the offerings available for wind power. Some commercial systems use weather and satellite products only available in particular regions (e.g. 10 minute update satellite imagery for the mainland USA). It would be complex to combine additional external commercial services with the AWEFS (itself a commercial system) but it may be possible to licence algorithms such as the satellite image processing scheme developed by Dr. Richard Perez at the University of Albany, NY. The developers of the current AWEFS system have offered an upgrade path to AEMO which handles solar forecasting (including satellite imagery techniques), the technology and accuracy of which would need to be evaluated. Often absent from the commercial offerings are expressions of uncertainties. Most are also limited to PV where the conversion models for radiation to power production are relatively well understood and the relationship more direct. The forecasting of output from CST generators and distributed PV are two areas where there is little information in the commercial offerings.

There is currently emerging international co-operation in areas relevant to solar energy production forecasting. There is a European COST[5] Action ES1002 (Weather Intelligence for Renewable Energy) – which seeks to support wind and solar forecasting and the interaction between highly intermittent generation and the energy distribution system (CSIRO is a member). The International Energy Agency has recently launched a subtask (IEA SHC Task 46) on Solar Resource Assessment and Forecasting with particular emphasis on understanding the variability characteristics. The task, operated by NREL from the USA, runs from 2011 to 2016 and includes contributions from 13 countries, including Australia with participation from CSIRO, Bureau of Meteorology and the University of South Australia who are involved in a number of subtasks.

3. The current status of SEF in Australia

To date there has been no comprehensive research and development program in solar forecasting in Australia. Research is fragmented and not co-ordinated. However a number of

[4] The European Centre for Medium-Range Weather Forecasts
[5] European cooperation in the field of Scientific and Technical Research (COST) – see www.cost.esf.org

studies have been undertaken or are being currently publicly funded. A DRET-funded feasibility study, undertaken by CSIRO in 2009, concluded that it was feasible in principle to extend the architecture of the AWEFS system to solar but that there needed to be significant development of some key solar forecasting components as well as comprehensive local validation studies. Also as part of the feasibility study the Bureau of Meteorology undertook a preliminary study of the accuracy of satellite-derived radiation estimates and NWP-based solar radiation forecasting in Australia, concluding that more validation work needed to be done, especially in cloudy conditions.

There are a number of new research solar-energy projects that are currently being funded, or are proposed which are of relevance to SEF:

- Geosciences Australia and the Bureau of Meteorology are being funded by DRET to add 8 new stations to the high-quality BoM solar monitoring station network (for 18 months), bringing the total to 17. They will also develop better analysis processes and revisit the historical data with those improved processes with the intention of gaining an improved quality 20yr solar exposure record covering Australia. This data will be vital for validating forecasting models, ground-truthing satellite observations and producing the longer-term statistics. There is also a separate proposal by BoM being considered by the ASI, to produce a public 1 minute data set from the monitoring stations. This could also be used to develop and test prediction models for short-term intermittency.
- The University of New South Wales in collaboration with the University of South Australia, APVA, Epuron and the BoM are being funded by the ASI to work on forecasting and characterising grid connected solar energy and developing synergies with wind. The project is exploring the relationships between predictable weather patterns and the generation characteristics of key intermittent solar renewable technologies. This will lead to site suitability metrics for these technologies as well as support the development of a real-time forecasting scheme for solar generation system output. Different modelling techniques will be utilised to predict future weather for a range of timescales, and techniques for deriving aggregated forecasts will then be developed.
- CSIRO is has been funded by the ASI to undertake a macro-level examination of the intermittency issue with the aim of distilling a clear understanding of how solar intermittency will likely affect Australian distribution and transmission systems. This work also seeks to understand how issues with intermittency in wind generation may apply to solar.
- CSIRO and BoM, in conjunction with NREL in the USA have been funded by the ASI to develop an integrated solar radiation data set including uncertainty estimates, based on a combination of in situ observations, satellite-derived data and, especially, high-spatial resolution model simulations, which would be used to address questions such as optimal deployment of ground stations and would also strongly enhance the ability to measure and characterize the expected output of MW scale solar power plants and thereby provide critical input to the planning, project finance and due diligence process for solar power plants at generic locations in Australia.
- CSIRO, in conjunction with NREL in the USA, Desert Knowledge Australia Solar Centre and Lend Lease, have been funded by the ASI to investigate the technical factors that impact energy output and drive revenue projections of different PV technology types

to help PV power plants become more economically viable. This includes the spectral properties of solar radiation and their effect on PV device performance.

Other research projects which have been proposed in previous ASI funding rounds, and reflect potential Australian capability, cover the following:

- Solar Energy Resources Studies;
- Validation of Numerical Weather Prediction Forecasts for Solar Energy; and a
- Solar Energy Time-series Simulator

There is clearly an emphasis on measuring and understanding the characteristics of solar energy generation especially through the improvement in our understanding of solar radiation and related meteorological processes. There are also some preliminary efforts in forecasting techniques, including intermittency characterisation. The real challenge is now to harmonise, utilise and expand on these efforts, assimilating and co-ordinating with overseas work.

4. SEF requirements in the Australian context

To provide robust operational forecasting capabilities for Australia a number of tasks need to be addressed.

- A review of existing and proposed overseas approaches to integrating solar energy forecasting into electricity supply systems
- A detailed assessment of current commercial offerings which could be entrained into the ASEFS architecture
- A detailed assessment of the status of many current overseas solar forecasting techniques
- The development or adaption of emerging techniques for short-term forecasting using local satellite imaging and on-ground sensor arrays, and testing in the Australian context
- The development of long-term statistical models for 2 year AEMO forecasting requirements (with uncertainties)
- Validation studies need to be undertaken for the Australian conditions leveraging the high-quality radiation datasets available, and including quantification of uncertainties as prescribed by AEMO, in the following areas:
    - currently available NWP radiation products (including DNI) at various time horizons – the primary input to ASEFS
    - any commercial forecasting offerings to be incorporated into ASEFS
    - any established forecasting methodologies proposed for the initial implementation of the forecasting system
    - radiation to power conversion models for PV.
- Work on conversion modelling for CST in conjunction with power station proponents
- Development of models for intermittency prediction

- Development of models for distributed solar production – including on-line data requirements and limitations. This model will need to take account of the varying data availability in each major city and/or region. Representative generating sites may need to be equipped with solar monitoring and made available as a live data feed to enable up-scaling to represent regional generation.

The quality of the observation systems is important. High quality observations are required for the validation studies. Quality on-site radiation observations are needed at large power stations. Lower quality observations are needed surrounding a large power station for short-term forecasting development. A network of radiation observations accompanying real-time monitoring of selected generating systems is required for forecasting of distributed generation.

5. Comments received on the ASI's ASEFS consultation document and feedback from the November 2011 SEF Workshop

In response to an invitation by the ASI to Solar Industry stakeholders to provide feedback on the ASEFS concept a limited number of written submissions (4) were received. The half-day workshop, held in November 2011 at the International Conference on Energy and Meteorology on the Gold Coast, also solicited much discussion and this is summarised in Appendix 1. Some key points from these submissions are provided below:

- There is value to be gained in leveraging off relevant activities underway internationally (e.g. link with relevant IEA Tasks, European "COST" action and solar forecasting work in other countries such as the USA and Germany).
- There was a general view that adequate solar forecasting techniques exist for use in an ASEFS; however the key challenge will be to assess which of these are most appropriate for the Australian context, and validating them with Australian data.
- Further work is required to determine in situ (i.e. at power plant) solar monitoring and forecasting requirements; however there appears to be a range of benefits that can potentially accrue from such data.
- Where possible an ASEFS should look to make use of existing solar data sources (e.g. from existing distributed PV plants). There may also be value in making existing data sources generally available in one location via a solar data web-portal which could essentially be a "pointer" to the different solar data source locations. This may also serve to help identify/collate what data sources are actually presently out there. The ASI may be able to help facilitate this.
- Similarly, a desire was expressed for data from the ASEFS (once developed) to be made as publicly available as feasible, and preferably through a single access point.
- Contact should be made with network service providers (distributors in particular) in developing an approach for solar forecasting for distributed PV, particularly in relation to distributed PV data collection.
- The general approach to be taken for forecasting power output from Concentrating Solar Thermal (CST) plants will require careful consideration given the particular characteristics of CST plants and the dependence of their power output upon such

factors as: plant complexity; thermal inertia; potential for co-firing and thermal storage capabilities; and method of plant operation.

Offers of participation and research collaboration were received from both local and overseas institutions via both the written responses to the ASI's request-for-comments document and during the SEF Workshop, from the following:

- **Australian Research Providers:** CSIRO, Bureau of Meteorology, University of NSW, University of Queensland, University of South Australia, Australian National University

- **Overseas Research Providers:** DLR (Germany), University Oldenburg (Germany), SERIS - Solar Energy Research Institute of Singapore, University of California - San Diego, NREL (USA), NCAR (USA), Fraunhofer Institute (Germany)

- **Companies:** Wind Prospect, UNLTD Energy, Green Power Labs Australia, Pacific Hydro

6. Key steps for development of an ASEFS

Based on the AWEFS experience, the development of an operational system when all the required elements are not yet proven requires a conservative and staged approach.

Informal feedback has been obtained from AEMO as to their required approach. To summarise the AEMO requirements - they will need three SEF data models to match their scheduling requirements (see Figure 3):

1. Short time frame - 5 minute interval, 2 hour horizon, every 5 minutes (50% probability of exceedance required)
2. Medium time frame - 30 minute interval, 8 day horizon, every 30 minutes (10%, 50%, 90% probability of exceedance)
3. Long time frame - 30 minute interval, 2 year horizon, every day (10%, 50%, 90% probability of exceedance)

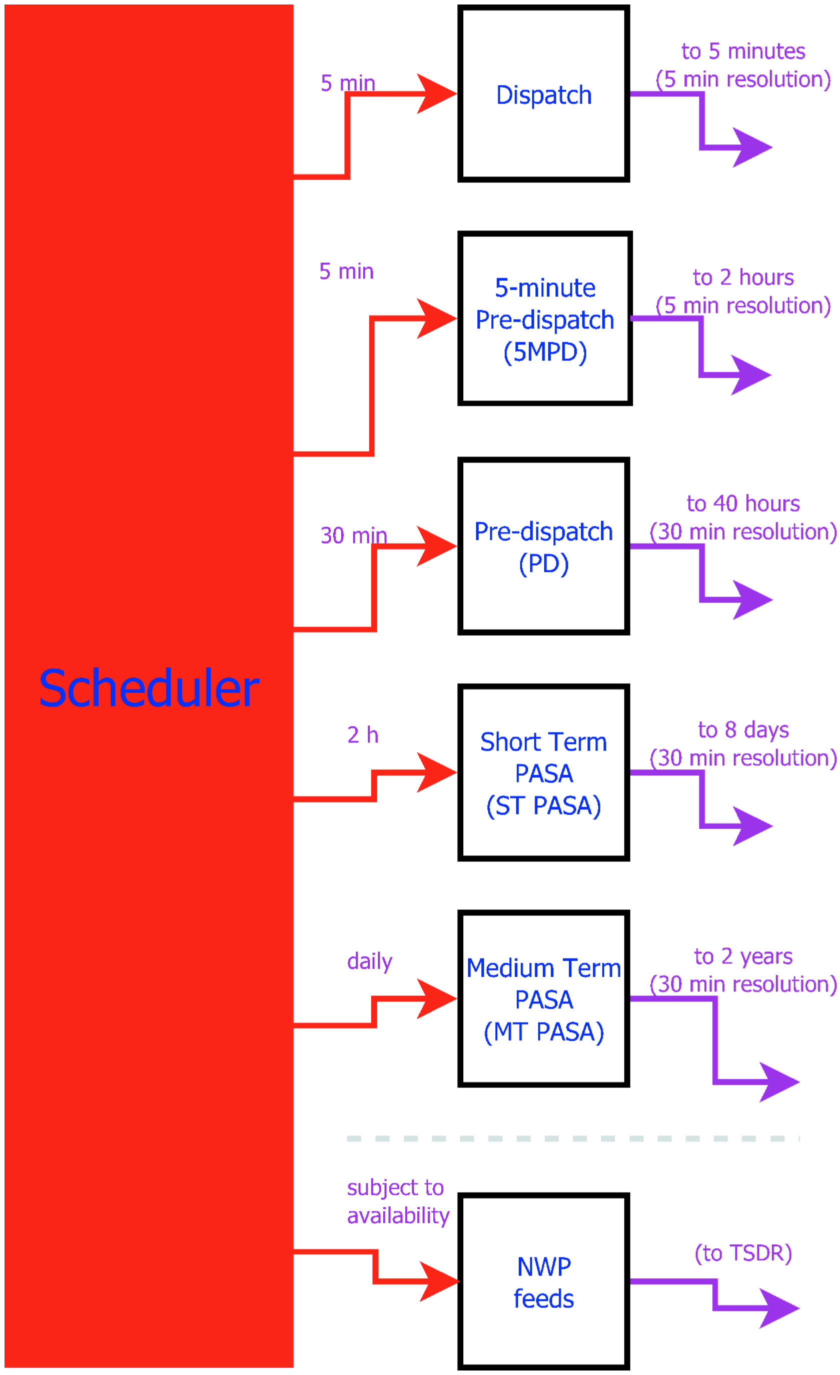

Figure 3 Scheduling within the AWEFS system (update timing shown on left of each prediction module; PASA - Projected Assessment of System Adequacy)

The existing AWEFS architecture is modular and can be adapted for the requirements for a solar energy forecasting. AEMO believe that commercial-grade solar forecasting models exist for the medium time frame, but only very simple schemes for the short and long time frames. They will require a minimum of the medium and long time frame models to commence operations. High amongst the identified areas of risk are the energy conversion models, both for PV and especially for CST. This will require discussion with power plant operators. They have also indicated that a SEF model for distributed solar production will need to be developed for each major Australian population centre. A basic ASEFS system needs to be in place before the commencement of operation of the large Solar Flagship plants.

As mentioned above, forecasts need to be available with the 10%, 50% and 90% probability of exceedance for all but the short time scale. Both the radiation forecasting components and the energy conversion models need to be included when establishing accuracy and providing forecasts with the required uncertainties. Testing and validation studies will need to be undertaken to provide these.

There will be a need for interaction with the AWEFS system architects in order to undertake modifications and incorporate any new algorithms. A formal process will need to be established to accommodate new techniques as they are proven. Developments will need to be validated, have a demonstrated cost-benefit and be packaged into modules suitable for ASEFS.

7. A proposed ASEFS implementation framework

The ASEFS implementation framework proposed here breaks the process into three broad phases (see Figure 1):

- Phase I – System design - Benchmarking – Implementation of baseline forecasting for PV, CST and distributed PV - covering all AEMO timeframes – completion in 18 months
- Phase II – Implementation of upgraded 0-24 hour prediction, improved distributed PV forecasting, intermittency and validation studies – 18 months to Year 3
- Phase III - Extended Validation – Advanced forecasting schemes – Years 3 to 5

The proposed specific tasks to be undertaken within each phase are listed further below. The timing of the work components is shown in Figure 4. The majority of the work is the specification, development, implementation and benchmarking of system components and the system platform. Additional work provides fundamental underpinning science and the development of elements which are at an earlier stage and needed proving before they can be production engineered.

Phase I – System Design - Benchmarking – Implementation of baseline forecasting – 18 months

1. Review of existing and proposed overseas approaches to integrating solar energy forecasting into electricity supply systems
    a. Detailed assessment/review of existing and proposed overseas approaches to integrating solar energy forecasting into electricity supply systems with levels of high solar penetration (e.g. USA, Germany, Spain)
    b. Detailed assessment of currently commercially available and potential solar forecasting techniques and their applicability to Australia

2. Define specification and determine changes to AWEFS architecture to implement Phase I based on following inputs:
    a. NWP simple (DNI, diffuse, other predicted met – temperature, wind..)
    b. Local SCADA and radiation observations, plant availability
    c. Other local met observations
    d. Data required for distributed PV forecast - data from monitored systems including met observations
3. Develop essential background validation; define data sets and metrics
    a. Validation Studies for radiation prediction performance of NWP feeds currently in AWEFS (DNI, diffuse radiation)
    b. Development of test data sets for forecasting system tender evaluation and forecasting development validation (radiation and power production)
    c. Organise central depository for data sets
    d. Development of suitable metrics and targets for tender evaluation and forecasting development validation
4. Implement architectural changes to AWEFS
    a. Data structures
    b. Procurement and organisation of data feeds (NWP and SCADA)
    c. Output data formats
5. Develop initial base-line radiation-to-power conversion models
    a. Large, steerable PV array – in conjunction with Moree consortium
    b. CST array - in conjunction with Solar Dawn consortium
    c. Initial distributed PV model using simple input data (estimated fleet, install small number of monitoring points)
6. Tender and install Phase I power forecasting capability, PV, CST, distributed PV at all time scales (note that solutions need to be run inside the current AWEFS system)
    a. Limited 5 min pre-dispatch (5minutes – 2 hour) based on SCADA
    b. Limited Short Term PASA (1 to 8 day ahead) - single site PV – NWP methods including uncertainties – trials of NWP methods to fill 2 hour to 1 day gap to establish baseline uncertainties.
    c. Medium Term PASA (daily to 2 years) – single site PV – statistical methods
    d. Evaluate using data sets and metrics developed above
    e. Noting that the 2 hour to 1 day gap could be filled by "old" NWP forecast
7. Determine range of inputs to be catered for in Phase II – outline implications for ASEFS architecture of
    a. Broader local met obs (including sky imaging and regional network)
    b. Satellite imagery
    c. Complex NWP fields (cloud type, synoptic class, other 2d and 3d fields which correlate to variability)
    d. Expanded output formats
8. R&D for Phase II implementation – emphasis on 0-24 hour ahead prediction for single-site, distributed PV, and intermittency
    a. Improved radiative-transfer modelling for NWP – including cloud schemes and aerosols
    b. Short term satellite-based schemes using locally available real-time data, combined with NWP

c. Short-term schemes based on on-site and peripheral met data and sky imaging
d. Basic forecasting schemes based on more complex NWP fields (cloud character, synoptic class)
e. Development of basic intermittency prediction schemes at all time scales
f. Investigation and testing of distributed PV generation data sets, testing and further development of distributed PV power prediction techniques

Phase II – Implementation of upgraded 0-24 hour prediction, improved distributed PV, intermittency and validation studies – 18 months to Year 3

1. Essential validation, establish base-line ASEFS forecasting accuracy and uncertainties
    a. Validation Studies for radiation prediction performance of NWP feeds implemented in ASEFS (DNI and diffuse radiation)
    b. Validation Studies for initial forecasting models at all time scales in ASEFS against agreed metrics
    c. Validation of power conversion models against plant data
    d. Validation of distributed PV model
    e. Development of more extensive test data sets
2. Implement architectural changes to ASEFS for Phase II
    a. Expanded SCADA feeds - local met obs (including sky imaging and regional network)
    b. Satellite imagery
    c. Complex NWP fields (cloud character, 2d and 3d fields which correlate to variability)
    d. Expanded output formats
3. Develop improved radiation-to-power conversion models
    a. Large, steerable PV array – in conjunction with Moree consortium
    b. CST array - in conjunction with Solar Dawn consortium
    c. More advanced distributed PV model using simple input data (accurate fleet data, install more extensive array of monitoring points)
4. Detailed evaluation of candidates for Phase III power forecasting capability upgrade against cost-benefit
    a. Improved radiative-transfer modelling for NWP – including cloud schemes and aerosols
    b. Short term satellite-based schemes using locally available data, combined with NWP
    c. Short-term schemes based on on-site and peripheral met data and sky imaging, as available
    d. Basic distributed PV power prediction techniques
    e. Intermittency prediction schemes at all time scales
5. R&D for Phase III implementation
    a. Radiative-transfer modelling for NWP
    b. Short term satellite-based schemes using new, high frequency Japanese satellite.

c. Short-term schemes based on on-site data now available from Solar Flagship plants
d. Advanced forecasting schemes based on more complex NWP fields (cloud character, synoptic class)
e. Advanced intermittency prediction schemes at all time scales
f. Testing and further development of advanced distributed PV power prediction techniques

Phase III - Extended Validation – Advanced forecasting schemes – Years 3-5

1. Implement forecasting upgrade candidates developed in Phase II when proven
    a. Improved radiative-transfer modelling for NWP – including cloud schemes and aerosols
    b. Short term satellite-based schemes using high frequency Japanese satellite data
    c. Short-term schemes based on on-site and peripheral met data and sky imaging available from Solar Flagship plants
    d. Advanced distributed PV power prediction techniques
    e. Intermittency prediction schemes at all time scales
2. Essential validation of ASEFS with forecasting upgrades
    a. Development of validation data sets from operational system
    b. Validation Studies for improved NWP feeds implemented in ASEFS
    c. Validation of short-term models (satellite and local data) against agreed metrics
    d. Further validation of power conversion models against plant data
    e. Validation of advanced distributed PV model
3. Further R&D based on experience from operational system
    a. In all areas described in 1, particularly as driven by operational experience – goal is to reduce uncertainties and improve accuracy

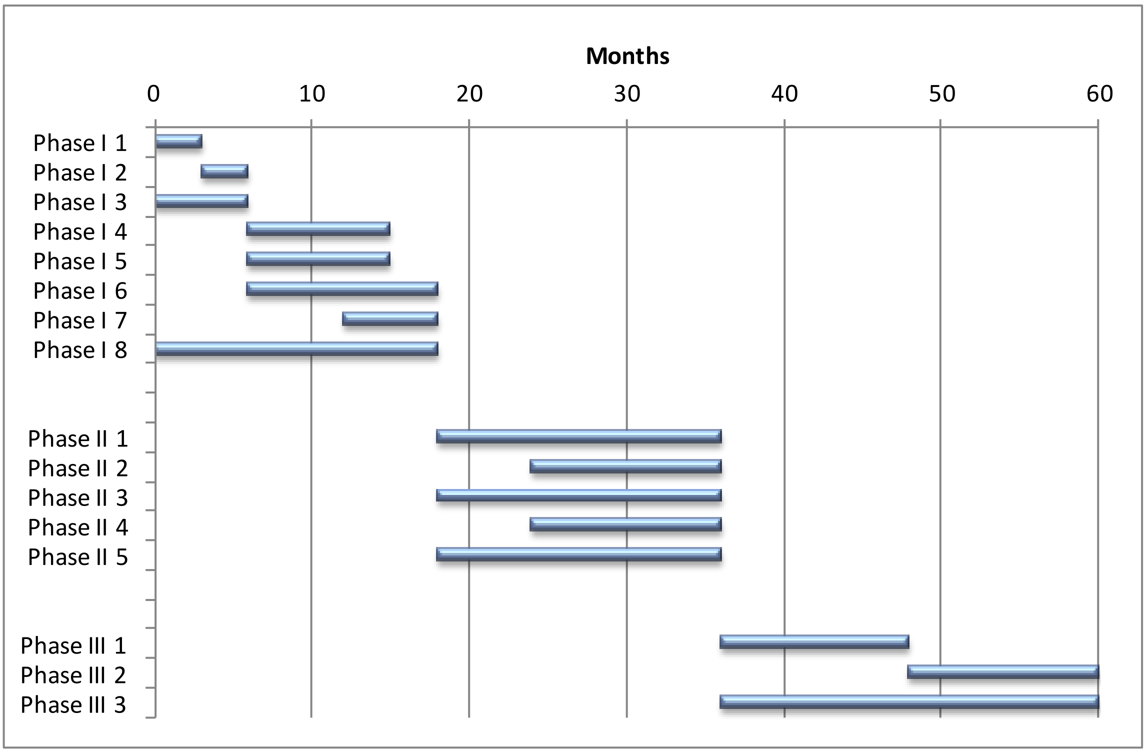

Figure 4 Timings for ASEFS work

8. Appendix 1 – Summary of Discussion Session at ASI SEF Workshop (Nov 2011)

ASI Solar Energy Forecasting Workshop
Summary of Discussion Session

Overview

This document contains a summary of key feedback noted during the stakeholder discussion session at the Australian Solar Institute (ASI) Solar Energy Forecasting (SEF) Workshop held on Friday 11th November 2011 at the International Conference on Energy and Meteorology (ICEM), Gold Coast, Queensland.

The aims of the workshop were to provide an overview of current SEF activities in Australia and to provide a forum for stakeholder discussion and feedback on the proposed Australian Solar Energy Forecasting System (ASEFS) and SEF R&D status and priorities generally.

The workshop was attended by approximately fifty people representing a broad range of Australian and overseas SEF stakeholder organisations from the research, industry and government sectors. The workshop consisted of presentations on key SEF-related projects and activities in Australia (note these are available on the ASI website at www.australiansolarinstitute.com.au/presentations.htm), followed by a discussion session.

The discussion session, facilitated by Dr. Peter Coppin of CSIRO, posed questions on the current status of SEF, particularly with respect to the proposed ASEFS, in the following broad topic areas:

- Forecasting inputs
- Forecasting techniques
- Power conversion models

There was a high level of interest in and support for the proposed ASEFS, and a broad range of input provided into the topics covered. Some key take-aways that appeared to emerge from the discussions included:

- There is value to be gained in leveraging off relevant activities underway internationally (e.g. link with relevant IEA Tasks and solar forecasting work in other countries such as the USA and Germany)
- There was a general view that adequate solar forecasting techniques exist for use in an ASEFS; however the key challenge will be to assess which of these are most appropriate for the Australian context, and validating them with Australian data.
- Further work is required to determine in situ (i.e. at power plant) solar monitoring and forecasting requirements; however there appears to be a range of benefits that can potentially accrue from such data.
- Where possible an ASEFS should look to make use of existing solar data sources (e.g. from existing distributed PV plants). There may also be value in making existing data sources generally available in one location via a solar data web-portal which could essentially be a "pointer" to the different solar data source locations. This may also serve to help identify/collate what data sources are actually presently out there. The ASI may be able to help facilitate this.

- Similarly, a desire was expressed for data from the ASEFS (once developed) to be made as publicly available as feasible, and preferably through a single access point.
- Contact should be made with network service providers (distributors in particular) in developing an approach for solar forecasting for distributed PV, particularly in relation to distributed PV data collection.
- The general approach to be taken for forecasting power output from Concentrating Solar Thermal (CST) plants will require careful consideration given the particular characteristics of CST plants and the dependence of their power output upon such factors as: plant complexity; thermal inertia; potential for co-firing and thermal storage capabilities; and method of plant operation.

A more detailed summary of the points raised during the discussion sessions against each of the SEF topic areas is provided in the next section.

The feedback received during the workshop will be used to help inform the Solar Energy Forecasting Review currently being undertaken by Dr. Coppin for the ASI, as well as to help inform the next stages of development of the ASEFS.

The proposed next steps for development of the ASEFS are:

(i) AEMO/ASI to initiate preparation of a more detailed ASEFS Specification. (target completion end Feb 2012)

(ii) Confirm process for funding development of the ASEFS, as budget availability and requirements become clearer (target end Q1 2012)

(iii) Confirm and finalise ASEFS specification and implementation (target early Q2 2012)

Key Points Noted During Discussion Session

1) Forecasting Inputs

a) Numerical Weather Prediction (NWP) data:

- A view was expressed that NWP forecasts in general are not yet accurate enough for solar energy forecasting applications and that further work is required internationally, particularly in the case of Direct Normal Incident (DNI) radiation in cloudy conditions.
- Generally it was felt that NWP-based, day-ahead forecasts of radiation in clear-sky conditions were reasonable
- Work was needed to evaluate the radiation prediction capabilities (particularly DNI) of the various NWP weather feeds in the current AWEFS system including ECMWF (Europe), ACCESS (Australia) and NCEP (USA).
- The ECMWF model is generally regarded as the most accurate, but this fact remains to be tested in terms of radiation components in Australia.

b) Satellite data:

- There are a number of existing short-term solar forecasting schemes that make use of satellite imagery to detect cloud movements and evolution. However some of these make use of frequent imagery available in the USA and Europe.
- Current satellite imagery updates in Australia are hourly, however a new Japanese satellite is planned for launch in 2014 which will provide higher resolution imagery at shorter intervals (10 minutes), and is likely to be of value as an input into an ASEFS.

c) In situ data (Sky Imagery and Local Monitoring)

- This is an area where further work and clarification is required generally.
- It was noted that the Consortium for the proposed Solar Dawn concentrating solar thermal (CST) project in Queensland is currently clarifying local monitoring and forecasting requirements with AEMO.
- The Bureau of Meteorology (BoM) says it would be very interested in using such in situ data for validating/improving its own weather models.
- It was stated that there is a general move globally towards ground-truthing of weather forecasting models using surface data and such in situ monitoring may be able to feed into this more broadly.
- There is a relevant IEA Task looking into this area that would welcome Australian input.
- An issue was raised around what level of co-ordination there should be regarding monitoring/data requirements for solar forecasting versus solar resource assessment (e.g. finance sector needs vs. developer vs. research vs. plant operator needs etc.)

  - Related to the above, the issue was raised of what level of monitoring equipment and data accuracy is required, and where best to place monitoring devices spatially.
  - It was noted that understanding the underlying solar resource is relatively straightforward, however understanding the effects of local clouds is the key challenge.
  - A commercial sector attendee stated that a key solar forecasting requirement for a large solar plant was to know, with 90% probability, the likelihood of clear sunny days occurring (to be able to schedule full generation for those days), and also the likelihood of strongly overcast days occurring (to be able to schedule maintenance for those days if required).
  - It was expressed that availability of in situ monitoring/forecasting data from the two proposed Solar Flagships power plants could be very useful to a range of SEF stakeholders for a variety of purposes. It is, however, not known at present what level of data will be made available. There may also be commercial sensitivities involved.
  - The potential of sourcing/collating data from other existing (e.g. distributed) solar systems was raised. It was pointed out that there are already some offerings providing this (e.g. www.pvoutput.org – a user supported system; and some commercial offerings).
  - It was suggested that a solar data portal could be developed (possibly via the ASI) which could be a pointer to the various solar data sources currently available.

2) Forecasting Techniques

- There was a general view that adequate forecasting techniques are currently available for use in an ASEFS, however these need to be carefully assessed and validated for their applicability/accuracy in an Australian context, particularly with regard to local input data availability.
- In terms of whether existing commercial SEF offerings could be incorporated into an ASEFS (as opposed to developing in-house ASEFS systems), this has not been ruled out by AEMO however AEMO would need to carefully consider any associated issues such as the subsequent level of dependency on any external services.
- It was observed that there will almost certainly be differences between techniques to be used for forecasting of distributed PV power versus forecasting for individual large-scale solar plants.
- There may also be further investigation required on the kind of solar data parameters required as input to the power conversion models. For example the wind power conversion models typically only require wind speed and direction as inputs, however solar conversion models may require more complicated inputs (e.g. DNI vs. diffuse, and spatially dependent data related to solar plant area and cloud effects)

- AEMO also pointed out that the National Electricity Market is divided into specific regions and that solar energy forecasts need to be aligned with those regions, and that this would be particularly relevant for the approach to be used for forecasting distributed PV.
- It was noted that auto-regressive models would need real-time access to solar power plant data. It was also noted that AEMO currently have 10-second SCADA feeds from wind power plants and so such data might be required/available for large-scale solar plants.

3) Power Conversion Models

a) For centralised PV plants:

- It was proposed that there is a relatively direct relationship between solar input and power output for PV plants that can be represented relatively accurately by power conversion models.
- However it was also stated that this issue is being looked at more closely in the US and questions are being asked about exactly how accurate some of the existing conversion models are.

b) For concentrating solar thermal (CST) plants:

- There were a number of comments around whether CST plant power output can be effectively modelled via power conversion models. This is due to the particular characteristics of CST plants including their inherent complexity, thermodynamic nature including thermal inertia, the impacts of operator decisions, and the potential for CST plants to incorporate co-firing and thermal storage, which greatly increase their dispatchability.
- It was stated that tests have been conducted under one of the IEA Tasks (46) on the accuracy of certain CST power conversion models, which produced significantly different results across the models (e.g. 20% difference in power output for different models of the same plant using the same input parameters).
- It was queried whether CST plants perhaps should be treated differently to PV and wind plants in the electricity market with respect to their dispatchability categorisation (e.g. as semi- or fully dispatchable plant depending upon capabilities) and whether power forecasting should be the responsibility of the plant operators in these cases. AEMO said this issue needed further consideration.

c) For Distributed PV:

- It was proposed that data collection may be the key issue to be addressed here.
- It was suggested that there would be value in working with electricity distribution authorities to obtain data for this purpose.
- There are also commercial and other PV system data collection and monitoring systems (e.g. as provided by PV system installers/suppliers) that may have useful data for this purpose.