5. The Choice of Reference Concentrators

It is a risky task to see the future of concentrating technology, if we take into account the past and present state of the art, and especially the non-existence of a market.

But after more than 20 years since the beginning of this PV alternative, at least the wrong ways have been eliminated and those with possibilities of commercial success can be envisaged albeit it distantly.

A revision of the historic records on theory and experiences on C-systems has led to the choice of five Reference Concentrators.

These selected configurations are summarised in this 5th Chapter regarding the optics, the receivers, the concentration ratio, the system size, the cooling method and the component assembling.

5.1 Reference Concentrator types

The choice is presented here. In the following paragraphs each choice is justified. Later the rejected C-systems are also analysed:

Type I: ***Point focus on a single solar cell (not a parquet of cells) Systems***
Type II: ***Large area Point focus Systems***
Type III: ***Linear Systems***
Type IV: ***Static Systems***
Type V: ***Compact mini point focus Systems***

5.1.1 Type I : Point focus on a single solar cell Systems

The characteristics of this C-System type are:

- Collector

Point Focus Fresnel lens.

In this group the use of secondary or focus uniformisers must be considered and included:

  - Secondary providing more aperture angle or more concentration ratio.
  - Secondary just to make the light uniform.
  - Both S1 and S2.

- Types of cell

Following types of cell must be considered in this reference type:

- Silicon cells
- III-V cells
- Several cells with spectral beam splitting (usually Si + III-V)
- Monolithic Multi-junction cells
- Multi-circuit Multi-junction cells

- Concentration Ratio

The range of geometric concentration for each class of preceding cell is limited to:

- $50 < X_g < 500$ for silicon cells
- $X_g > 500$ for all other cells

(The cell technology is currently more limiting than the optics)

- Cooling

Passive cooling can be suitable for very small cells up to 1000 suns as they are separated individually.

However active cooling cannot be clearly discarded as the performance and thermal requirements of the forthcoming materials and cells that will probably operate at 1000 suns are not yet known.

- Tracking

All the preceding systems will require accurate 2-axis tracking, with better than +/- 0.2 control tracking accuracy to lead to a practical 1º half-aperture angle.

5.1.2 Type II: Large area point focus Systems

In this group are included:

- The big or medium size parabolic dishes
- The receivers of central tower power plants

The first are the most likely candidates.

The spot of light produced by these systems is large, thus requiring a parquet of receiving cells, mounted contiguously, interconnected at the back, and requiring active cooling due to the quasi–one dimensional geometry of the receiver.

The characteristics of each component for this C-System type are described below:

- **Cell types**

Very small cells are not suitable for these systems due to excessive interconnects and edge loses. But the high concentration levels limit the size from 1 to 3 cm^2.

Suitable material is the same as for the previous group assuming the size of 1 cm^2 is achieved.

- **Concentration ratio**

Due to the optical and thermal limitations of large PV dish systems it should range from 150 to 500.

For central towers the concentration can reach 2000 suns but it is not clear whether this power density could be useful.

Secondaries and /or light uniformizers (spreaders) will be required.

- **Cooling**

Cells must be mounted on compact arrays prepared for active cooling and electrically interconnected.

- **Tracking**

Requires 2-axis tracking (or heliostat mode for central tower).
For a parabolic dish, astronomical-based tracking combined with direct sun-dish tracking must be adopted. Accuracy must be better than 0.05 degrees (0.8 mradians).

5.1.3 Type III: Linear Systems

Are those providing a focus line.

The following are included this group:

- Linear Focus Fresnel lens

- Parabolic troughs

Secondaries, both linear and 3D, can be adopted for making light uniform, aperture increase and further geometrical concentration ratio gain.

Linear secondaries contribute mainly to reducing optical mismatch and provide some gain (2-3X).

3D secondaries allow a significant increase in the concentration ratio (up to 10X) without degradation of the aperture.

The characteristics of the System components are detailed below:

- **Cell types**

The basic linear C-systems, without secondaries, requires the use of large Silicon cells (20 to 100 cm2) to achieve economic viability.

Linear secondaries increase the concentration ratio but not enough to justify using other cells other than Silicon.

However the adoption of 3D concentrators at the receivers makes the III-V cells acceptable for linear systems at achievable > = 300X.

- **Concentration**

Concentration level of primary for those systems is in the range of 15 to 60 suns, but reaching till 300X with 3D secondaries.

- **Cooling**

Active and passive cooling is suitable for these systems. The requirements for cooling are significant.

- **Tracking**

Linear lenses require 2-axis tracking (except at very low concentration ratios that are possibly not economically advisable).

Mirrors can adopt either one-axis tracking configuration or two-axis configurations.

5.1.4 Type IV: Static Systems

Are those able to collect and concentrate direct and diffuse radiation.

Optics and interconnection (encapsulation) are usually as related as in a conventional flat module: The concentrator is a simple unit like the flat module.

- **Type of cells**

Only silicon bifacial and mono-facial cells can be considered suitable for such concentrators.

- **Concentration ratio**

The ratio of concentration ranges from 1,5 to 10. Larger concentration levels require too many position adjustments to be considered static.

- **Cooling**

Active cooling and its associated piping cannot be economically justified in these devices. But some passive cooling can be achieved using the collector plate as a heat sink.

5.1.5. Type V: Compact mini point focus Systems

The new families of high efficiency multi-junction solar cells are currently operating at very high concentration, in the range of 1000 suns, in order to dilute the high cost of such devices.

This level of concentration imposes a limitation on the size of the device for thermal reasons. And finally as the size of the cell is very small, in the range of 1 to 5 sq. mm, the size of the concentrator becomes small and the focal distance is also short (because the f/number must range from 1 to 2).

This kind of receiver, whose depth will range from 5 to 10 cm. is suitable for multi-cell encapsulation, including the lenses or the small dish, the cells, the secondaries, the heat sinks, the interconnections and the by-pass diodes in the same box.

The final aspect of this panel will be a closed housing (such as a low temperature flat thermal module) with just mechanical fixtures and a connection box.

The testing of these concentrator modules should be carried out, probably, in a way different from conventional concentrators, in which the collectors, receivers, etc. can be manufactured separately and their partial characteristics specified.

In summary, as the multi-junction cells require a specific control of the spectrum and also a special encapsulating arrangement, we think expedient to consider “Compact mini“ as a type of reference concentrators.

This concept includes:

- Small lenses.
- Small parabolic dish.
- Combinations of refractive & reflexive & internal reflection devices with revolution symmetry providing point focus (RXI).

- **Type of cells.**

Suitable material is the same as groups I and II.

- **Concentration ratio**

The concentration ratio is in the range of 1000 X

- **Cooling**

Passive

- **Tracking**

Two-axis tracking is required.

5.2 Types of Concentrators excluded

Luminescent concentrators have not reached the minimum efficiencies to justify their use in Photovoltaic due to the degradation of dyes.

Luminescent was considered interesting as it can be used as architectonic elements in windows, roofs, etc. However the thin films of today offer the possibility of transparency that is required to windows and are already providing more efficiency than the concentrators. On the other hand, cooling the cells located on the edge is difficult to implement if a compact panel to panel contiguous arrangement is used.

Finally dyes in glass were still more ineffective than dyes in plastic matrix (ethyl-methacrylate). Thus the interest for long life photo-luminescent PV windows is still smaller.

Thermo-photovoltaic systems will gain attention in the 6th Photovoltaic Program of the EC as they are theoretically able to convert the whole spectrum in energy.

However the lack of experience with modern cells and thermal devices do not allow to define standards, nor specifications for these systems. In consequence they are not included in the C-rating project.

TABLE 5.1 CHARACTERISTICS OF REFERENCE CONCENTRATORS

REFERENCE CONCENTRATOR	Optics	Cell Assembly	Cell Type	Concentration ratio	Cooling	Tracking
POINT FOCUS ON A SINGLE SOLAR CELL SYSTEMS	Fresnel Lens	One single cell Or Several cells with spectral beam splitting	Uni-junction Silicon Or Uni-junction III-V Or Multi-junction	50 < Xg <500 for Silicon cells >500 for all other cells	Passive (Note 1)	Two-axis
LARGE AREA POINT FOCUS SYSTEMS	Big or medium size parabolic dish. Or Central tower power plant	Parquet of cells	Uni-junction Silicon Or Uni-junction III-V Or Multi-junction	150 < Xg <500	Active	Two-axis
LINEAR SYSTEMS	Linear lens Or Parabolic trough	Linear array of cells	Silicon Or III-V (With 3D Secondary)	15< Xg < 60 (Without Secondary) 60< Xg < 300 (With Secondary)	Passive	One-axis for parabolic troughs. Two-axis for lenses.
STATIC SYSTEMS	Non imaging device	Usually linear array of cells	Silicon	1,5< Xg < 10	Passive	No tracking
COMPACT MINI POINT FOCUS SYSTEMS	Small lens Or Small Parabolic Dish Or RXI device	One single cell	Uni-junction Silicon Or Uni-junction III-V Or Multi-junction	Xg > 800	Passive	Two-axis

Note 1 Active cooling cannot be discarded for systems with a high Concentration ratio

ANNEX 1 References

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