Assessment of power generation performance characteristics using different solar photovoltaic technologies

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Abstract. Solar energy is a relatively free renewable, clean, green, and environmentally friendly energy resource produced from the sun, using different technologies like solar thermal and photovoltaic (PV) modules to generate heat and electricity, respectively. This paper aims to assess and compare the power generation performance characteristics of different solar PV module technologies by simulation, deploying identical input temperature and irradiance parameters. The solar PV designs were simulated using PVsyst Version 6.73 for 26.0 kW annual power and 42.9 MWh/year annual yields using the climate data of Sydney, Australia. The results show that monocrystalline solar technologies needed an area of 163m², while polycrystalline and thin film technologies needed areas of 173m² and 260m² respectively to generate 42.9 MWh annual yield. The monocrystalline PV modules are more efficient at solar energy conversion than polycrystalline and thin film technologies, respectively (94.2% and 62.7%). The symmetric semi-toroid dome of sun heights against azimuthal angles show 13 bimodal pyriforms, that cut the azimuths at least twice on each of the optimisation lines. These optimal solution points were visible for every sunlight hour of between 6 and 18 hours (inclusive). They show convex sets of global optima (or local optima) with one minimum in the interval of convexity. Also, each of the minimum points for each of the 13 directed fish-like bimodal pyriforms was on ±60° azimuth. However, the assessment of respective PV module characteristics with respect to variation of irradiation and temperature, show that the general results from simulation displayed disparate changes in the voltages and currents of the generated power with respect to different solar PV modules. The proposed semi-toroid model indicates that many optimisation solutions for easier, cheaper, quicker and more efficient power generation are possible with appropriate design. It is recommended that the installation of a single-axis solar tracker or maximum power point tracker could overcome the azimuth angle effect.

1. Introduction
Clean Energy can be generated from the naturally available free sunlight using different technologies. Photovoltaic (PV) solar modules generate electricity from solar energy through the photovoltaic effect.
Photovoltaic solar cells are the basic units of the PV solar system and they are made of semiconductors materials. PV cells are doped semiconductor materials which form positive-negative (P-N) structures with internal electric fields. The p-type (positive) silicon can easily give up electrons and become holes (protons) while the n-type (negative) silicon readily gains electrons to become more negatively charged [2]. Whenever sunlight strikes solar cells, the photons (light) stimulate some of the electrons in the semiconductors to become electron-hole (negative-positive) pairs. The electron-hole pairs in the internal electric fields are influenced to separate into charges. Thus, electrons move towards the negative electrode (cathode) and the holes move towards the positive electrode (anode). A conducting wire connects the cathode, the load, and the anode in series to form a circuit. Hence, an electric current is generated to supply the external load [2]. Solar panel or solar module is the combination of multiple solar cells connected together and a solar array is the combination of multiple solar panels or solar modules in concert [3]. The generation performance and other electrical characteristics of PV solar modules depend on: weather conditions and the respective solar module technology. The technologies considered include monocrystalline, polycrystalline and thin film (CdTe, Amorphous, CIGS). The further, Cadmium telluride (CdTe) thin film uses compound cadmium telluride as the semiconductor material in PV solar cells to convert sunlight into direct current electricity. Also, the copper indium gallium selenide (CIGS) solar cell converts sunlight into electric power [4-6].

The PV cell saturation current varies with temperature as:

\[
I_0 = I_{0R} \times \left( \frac{T_c}{T_{ref}} \right)^3 \times e^{\left( \frac{qE_g}{kN} \left( \frac{1}{T_{ref}} - \frac{1}{T_c} \right) \right)}
\]

(2)

Where \(I_0\) is output current, \(I_{0R}\) is PV cell reverse saturation current at reference temperature \(T_{ref}\), \(T_a\) is ambient temperature, \(T_c\) is working temperature, \(G\) is solar irradiance, and \(NOCT\) is nominal operating cell temperature. \(E_g\) is band gap energy of semiconductor used in the cell. \(N\) which is the ideality factor depends on the PV manufacturing technologies. Equation 2 shows that the solar cell diode reverse saturation current grows exponentially as the third power of the ratio of the working temperature to the reference temperature.

\[
V_{OC} = \frac{NKT}{q} \ln \left( \frac{I_{ph}}{I_0} + 1 \right)
\]

(4)

\[
P_{max} = V_{mp} \times I_{mp} = FF \times V_{OC} \times I_{SC}
\]

(5)

\[
\eta = \frac{P_{max}}{P_{in}} = \frac{l_{mp} \times V_{mp}}{l(t) \times A_c}
\]

(6)
Where $V_{OC}$ is the open circuit voltage, $I_{SC}$ is the short circuit current, $P_{max}$ is the maximum power, FF is the fill factor, $I_{mp}$ is the maximum current and $V_{mp}$ is the voltage at maximum power. $\eta$ is the efficiency, $P_{in}$ is input power, $I(t)$ is incident radiation (W/m$^2$), $A_c$ is PV collector area (m$^2$).

2. Methodologies

Three solar PV module technologies (Monocrystalline, Polycrystalline and Thin films) were simulated using PVsyst Version 6.73 on a grid connected solar PV system of 26.0 kW annual power and 42.9 MWh/year annual yield. The analyses used the climatic weather data of Sydney, Australia (-33.87° Latitude, 151.20° Longitude, 4 Altitude, 10.0 Time zone). Figure 2 indicates the geographical coordinates of Sydney, Australia, which is our test laboratory, while Figure 3 shows the average monthly global irradiance, diffuse power, temperature, and wind velocity data. These were simulated on the PVsyst Version 6.73 using 30° collector plane angle tilt and 0° azimuth angle. They were implemented using the same parameters to enable us obtain comparable characteristics for amorphous, monocrystalline, polycrystalline and thin films (CdTe, and CIGS) solar PV technologies in the study.

3. Simulation results

The results of the study are displayed in figures 4-11. Figure 4 shows annual irradiance bar charts for Global horizontal (GHI) and Global on tilted plane irradiances (GTI). GHI is the total shortwave radiation directly incident upon the horizontal surface parallel to the ground. It is vital to PV installations and includes direct normal irradiance (DNI) and diffuse horizontal irradiance (DIF) [12]. Further, GHI is the addition of direct and diffuse radiation received by a horizontal surface. It is used to compare climatic zones and for the computation of radiation on a tilted plane [13]. Figure 5 shows a symmetric dome of sun heights $[0 - 90^\circ]$ against azimuthal angles $[-120^\circ \leq \theta \leq +120^\circ]$. There were 13 fish-like bimodal pyriforms [13-14] that cut the azimuths at least twice on each of the $\pm 60^\circ \leq \theta \leq \pm 120^\circ$ optimisation lines. These optimal solution points were visible for every sunlight hour of between 6 and 18 hours (inclusive). These 13 fish-like plots are (0, 1) problems of convex sets, that consists of global optima (or local optima) with one minimum in the interval of convexity [15-16]. Also, each of the minimum points for each of the 13 fish-like bimodal pyriforms were on $\pm 60^\circ$ azimuth. Additionally, Figure 5 is a semi-toroid whose advantages include higher efficiency, lower operating temperature and lower noise. If we use the toroidal transformer analogue to explain this diagram, it shows that the resultant better equipment design and improved procedures makes it provide several performance advantages. It is a more affordable solution to new and more stringent requirements [17]. This is so because the size of a transformer is proportional to the square root of the total transformer power. Thus, the toroidal core shape enables size reduction and weight of transformer by between 20 and 50%, compared to conventional cores without sacrificing performance. Also, core loss in toroids lies between 10 and 20% of the total power loss [17]. Further, the toroid shape results in a stable, predictable core that is free from holes, clamps, gaps and discontinuities.
These lead to higher efficiencies because toroids are about one half the size and weight of conventional transformer. Therefore, a semi-toroid would be a quarter the size and weight of a standard transformer. Analogously, the efficiency of a semi-toroid should double that of a toroid. And, hence, quadruple the efficiency of a conventional transformer, if efficiencies were to be linear [17]. While toroids require about 1/16 the electricity (excitation power) by the laminated (EI) or transformer in standby mode, it takes less energy to maintain the magnetic field in a toroidal core [18]. The flexible dimensions of toroids provides a mechanical benefit for manipulating the height and diameter, while keeping the cross-section constant, to suit different applications. Also, easy mounting, which derives from using a single centre bolt to mount the toroid. Consequently, the toroidal shape of the azimuth enables quicker and easier mounting that reduces photovoltaic modules assembly time [18]. Conversely, toroidal transformers radiate 1/10 the magnetic field of laminated transformers, because of their inherent efficiency and unique construction. While the windings cover the core as a shield, the magnetic field is contained within the envelope in transforming energy from primary to secondary (that means sunlight to direct electricity in Fig. 5 in PV module, within the azimuth toroid envelope). The magnetic field shielding effect in toroids makes special shielding requirements unnecessary, and makes the more useful for sensitive applications like low power electronics and medical instrumentation [18]. The most important and significant advantage of toroidal transformer is its efficiency, that derives from the tape wound grain orientation. The core is continuous and wound like a clock spring in tension. The magnetic field is oriented towards the same direction. This directional orientation of the magnetic field is very apparent in all the 13 bimodal pyriforms (all pointing to the top left in the direction of greater efficiency) [18]. The absence of gaps results in a stacking factor of 97.5% of its weight. Nevertheless, the symmetrical spread over the entire core makes higher flux density possible. Hence, the magnetic flux in the same direction enables high electrical efficiencies in the range 90% < η ≤ 98% [18].

Figure 6 comprises the 30° collector plane orientation tilt angle to enable simulation to be conducted based on the same initial conditions and parameters. This process provides a credible and an unbiased comparison. Figures 7a & b show the I-V and P-V characteristics of the Canadian solar CS5T-130M monocrystalline solar PV module. Figures 8a & b depict the I-V and P-V characteristics of Znshine PV-Tech ZXP6-72-300-P polycrystalline solar PV module. Also, figures 9a & b indicate the I-V and P-V characteristics of First Solar FS-280 CdTe solar PV module. Additionally, figures 11a & b show the I-V and P-V characteristics of Amorphous, Bosch Solar Energy c-SiM72NA41126300Wp solar PV module. Figures 10 a & b reveal the I-V and P-V characteristics of CIGSTSMC Solar TS-145 C1, CIGS PV module technologies [19].

**Table 1.**

| Site | Sydney (Australia) | Data source | MinedHorn 7.1 station |
|------|-------------------|-------------|----------------------|
|      |                   |             |                      |
| Global ins. | Diffuse | Temp. | Wind Vel. |
| (W/m²) | (W/m²) | °C   | (m/s) |
| January | 279.7 | 114.7 | 23.3 | 3.00 |
| February | 269.9 | 118.5 | 22.6 | 3.40 |
| March | 257.0 | 129.9 | 20.8 | 3.09 |
| April | 224.5 | 55.1 | 17.7 | 2.71 |
| May | 125.5 | 26.8 | 14.6 | 2.00 |
| June | 130.0 | 42.4 | 11.0 | 2.00 |
| July | 127.9 | 65.2 | 11.0 | 2.71 |
| August | 149.3 | 62.0 | 12.7 | 3.00 |
| September | 178.9 | 74.6 | 16.1 | 3.30 |
| October | 221.0 | 97.7 | 10.6 | 3.20 |
| November | 249.0 | 129.9 | 20.2 | 3.19 |
| December | 291.0 | 117.2 | 22.3 | 3.90 |
| Year | 191.2 | 80.1 | 17.6 | 3.2 |

**Figure 3.** Climatic weather conditions on the simulated site.

**Figure 4.** Annual Irradiance on the simulated site.
Figure 5. Horizontal Line drawings for the simulated site.

Figure 6. Collector Plane orientation for the simulated site.

Figure 7. Characteristics of the Monocrystalline solar module used in the simulation.

Figure 8. Characteristics of the Polycrystalline solar module used in the simulation.

Figure 9. Characteristics of the CdTe solar module used in the simulation.

Figure 10. Characteristics of the Amorphous solar module used in the simulation.
Figure 11. Characteristics of the CIGS solar module used in the simulation.

The simulations were performed on a flat rooftop, free standing grid connected system made of standard solar modules. The simulation results show that the monocrystalline solar modules needed an area of 163m², while the polycrystalline and thin film technologies needed areas of 173m² and 260m² respectively, to be able to generate 42.9MWh annual yields. Using the monocrystalline PV as a standard conversion unit, then the conversion efficiency of the polycrystalline module was 94.2% and that for thin films was 62.7% of the monocrystalline PV module.

The assessment of several power generation performance characteristics of different solar PV module technologies were compared by simulation in MATLAB using the detailed model of a grid connected PV array developed by Pierre Giroux and Gilbert Sybille [20]. This Matlab model was deployed in the study of this paper using five solar modules of different technologies (Monocrystalline, Polycrystalline, Thin films (CdTe, Amorphous and CIGS) with their technical specifications:

a. Monocrystalline
Model: Canadian Solar CS5T-130M
Pmax at STC: 130W, Vmp: 29.2V, Imp: 4.45A, Voc: 36.3V, Isc: 4.82A, power tolerance:-0.45%/°C
b. Polycrystalline
Model: Znshine PV-Tech ZXP 6-72-300-P
Pmax at STC: 300W, Vmp: 36.95V, Imp: 8.12A, Voc: 44.95V, Isc: 8.64A, power tolerance:-0.45%/°C
c. Thin film
1) Model: Cadmium Telluride, First Solar FS-280,
Pmax at STC: 80W, Vmp: 71.2V, Imp: 1.12A, Voc: 91.5V, Isc: 1.22A, power tolerance:-0.25%/°C
2) Model: Amorphous, Bosch Solar Energy c-Si M72NA41126300Wp
Pmax at STC: 300W, Vmp: 37.5V, Imp: 8A, Voc: 46V, Isc: 8.44A, power tolerance:-0.36%/°C
3) Model: CIGS TSMC Solar TS-150C1
Pmax at STC: 150W, Vmp: 48.1V, Imp: 3.12A, Voc: 62.5V, Isc: 3.45A, power tolerance:-0.28%/°C

PV arrays delivering maximum power of 42.0 kW, 99.0 kW, 26.0 kW, 99.0 kW, 49.0 kW at 1000 W/m² respectively, and monocrystalline, polycrystalline, CdTe, Amorphous and CIGS solar module technologies were used in simulation. These generations occurred when each module was connected separately to a 25 kV grid via a DC-DC boost converter and a three-phase level voltage Source Converter [16]. In these simulations, the PV array consists of 66 strings of 5 series-grid connected modules that were connected in parallel.
The simulation results about Pmp and Vmean for the arrays in different conditions were recorded as follow:

| Technologies | Monocrystalline Arrays |
|--------------|------------------------|
| Conditions   | 1000W/m², 25°C | 250W/m², 25°C | 1000W/m², 50°C |
| Pmp          | 50.4 kW      | 17.3 kW      | 38.0 kW      |
| Vmp          | 173.4 V      | 145.8 V      | 127.7 V      |

| Technologies | Polycrystalline Arrays |
|--------------|------------------------|
| Conditions   | 1000W/m², 25°C | 250W/m², 25°C | 1000W/m², 50°C |
| Pmp          | 74.6 kW      | 30.6 kW      | 53.8 kW      |
| Vmp          | 207.1 V      | 175.5 V      | 155.0 V      |

| Technologies | CdTe Arrays |
|--------------|-------------|
| Conditions   | 1000W/m², 25°C | 250W/m², 25°C | 1000W/m², 50°C |
| Pmp          | 26.0 kW      | 6.9 kW       | 24.2 kW      |
| Vmp          | 340.4 V      | 360.0 V      | 330.8 V      |

| Technologies | Amorphous Arrays |
|--------------|------------------|
| Conditions   | 1000W/m², 25°C | 250W/m², 25°C | 1000W/m², 50°C |
| Pmp          | 108.6 kW      | 24.2 kW      | 86.9 kW      |
| Vmp          | 222.8 V      | 180.4 V      | 160.2 V      |

| Technologies | CIGS Array |
|--------------|------------|
| Conditions   | 1000W/m², 25°C | 250W/m², 25°C | 1000W/m², 50°C |
| Pmp          | 49.5 kW      | 13.0 kW      | 44.4 kW      |
| Vmp          | 242.7 V      | 255.3 V      | 221.5 V      |

The simulation scenarios observed the impact of temperature and irradiance on different solar PV technologies. For the Monocrystalline array technology, the change in irradiance from 1000W/m² to 250W/m² while keeping the temperature constant at 25°C made the Pmp to decrease by 65.6% and Vmp to decrease by 15.9%. A change in temperature from 25°C to 50°C, while keeping the irradiance constant at 1000W/m² made the Pmp to decrease by 24.6% and Vmp to decrease by 26.3%. For the polycrystalline array technology, the irradiance change from 1000W/m² to 250W/m² and keeping the temperature constant at 25°C caused the Pmp to decrease by 59.0% and Vmp to decrease by 15.2%. A change of temperature from 25°C to 50°C and keeping the irradiance at 1000W/m² caused the Pmp to decrease by 27.8% and Vmp to decrease by 25.2%. For the CdTe array technology, a change in irradiance from 1000W/m² to 250W/m² and keeping the temperature constant at 25°C caused the Pmp to decrease by 73.5% and Vmp to increase by 5.7%. A change in temperature from 25°C to 50°C and keeping the irradiance at 1000W/m² caused the Pmp to decrease by 6.9% and Vmp to decrease by 2.8%. For the Amorphous array technology, a change in irradiance from 1000W/m² to 250W/m² and keeping the temperature constant at 25°C caused the Pmp to decrease by 73.7% and Vmp to increase by 5.2%. Also, a change in temperature from 25°C to 50°C and keeping the irradiance at 1000W/m² caused the Pmp to decrease by 20.0% and Vmp to decrease by 28.1%. For the CIGS array technology, a change in irradiance from 1000W/m² to 250W/m² and keeping the temperature constant at 25°C caused the Pmp to decrease by 73.7% and Vmp to increase by 5.2%. Further, a temperature change from 25°C to 50°C and keeping the Irradiance at 1000W/m² caused the Pmp to decrease by 10.0% and Vmp to decrease by 8.7%.

4. Discussions
The azimuth angle is the compass direction from which the sunlight comes. The sun is always directly south in the northern hemisphere and directly north in the southern hemisphere at solar noon. Thus, the
azimuth angle changes throughout the day. In addition, the azimuth angle changes with the latitude and time of the year. The azimuth angle is like a compass for direction, in that North = 0° and South = 180° or alternatively, ±180° and South = 0° [21]. A wrong azimuth angle selection could reduce the energy output of a solar PV array down by 35%. The azimuth is the PV array’s east-west or north-south orientations in degrees. An azimuth of zero is facing the equator in both the northern and southern hemispheres [22]. Thus, between latitudes 23° and 90° in the northern hemisphere, the sun is always in the South. So, modules on an array are directed to the South to obtain the most out of the sun’s energy. For Sydney, Australia in the southern hemisphere, PV modules on an array are directed to the north to enable them secure the most energy from the sun. Unfortunately, the magnetic compass does not normally point to the true north. This is so because complex fluid currents of iron, nickel and cobalt flow near the outer core of the earth to produce a magnetic field, to be compensated for [20]. To obtain more power generation from our insolation analyses, the meteorological conditions of Sydney, Australia are important factors to consider. Also, shading effects are considered if there is significant morning or afternoon shades at specific locations like trees, chimneys, buildings or nearby high hills in the locality. Thus, appropriate azimuth angle selection could compensate for energy loss due to shading effects [11,13,19-20]. Arguably, the installation of a solar PV system, single-axis solar tracker or maximum power point tracker [23] could overcome the azimuth angle effect [20]. Further, the results show that monocrystalline solar modules needed an area of 163m², while polycrystalline and thin film technologies needed areas of 173m² and 260m² respectively, to be able to generate 42.9MWh in annual yields. Upon taking the monocrystalline area as a standard of unit, the sunlight conversion efficiencies polycrystalline and thin film technologies, respectively become 94.2% and 62.7% in terms of monocrystalline PV modules. The direct radiation from the sun is that component that was neither reflected nor scattered, but reaches the surface. The component that was scattered by the atmosphere reaches the ground as diffused radiation. A small proportion of the radiation is reflected by the surface and reaches an inclined plane is the reflected radiation. The three radiation components of directed, diffused and reflected radiation form global radiation [12]. The direct normal irradiance (DNI) is a straight line representation of solar radiation coming directly from the sun at its present position in the sky. DNI is the quantity of solar radiation received per unit area by a surface normal to the rays coming directly from the sun at its present position in the sky [12]. Therefore, we can maximise the irradiance quantity annually by keeping its surface normal to incoming radiation [12]. DNI is also the component necessary in PV concentration technology (Concentrated Photovoltaic, CPV) [13]. The diffuse horizontal irradiance (DIF) is solar that is scattered or dispersed by molecules and particles in the atmosphere, that comes equally in all directions. It is the quantity of radiation received by a surface per unit area without shade or shadow and it is spread in all directions by molecules and particles in the atmosphere [12]. Further, the Global Tilted Irradiation/Irradiance (GTI) or total radiation received by a surface with specified tilt and azimuth, fixed or sun-tracking. It comprises a reference or standard in PV applications that can be hampered by shadow [11, 13]. The next section discusses the pyriforms on the semi-toroid. Each of the directed pyriforms was pointed to the left hand side towards the lobe of greater efficacy. There were also decreases in the sizes of the pyriforms as the moved further away from the 12 hour period on both sides of the semi-toroid [17, 18]. The compact sizes, coupled with both height and diameter flexibility makes the semi-toroid shape amenable to many and diverse applications. The mechanical advantage derives from the constraints of keeping the cross-section constant. The other ability of being able to contain the flux density within the toroid core and envelope makes shielding unnecessary and gives loss reduction benefits that contribute to higher performance efficiencies [17-18]. The size benefits of the semi-toroid leads to lower construction and installation cost, aside from higher efficiency components. The toroid shape provides a stable and predictable core that is free from encumbrances like holes, clams, gaps and discontinuities that could result in irregular heating and hot spots. The hollow in the semi-toroid also provides some air-insulation advantage by convection, that ultimately increases cooling, reduces core losses and increases efficiency [17-18]. The semi-toroid requires about 1/16 excitation power in standby mode and radiates 1/10 the magnetic field of the laminated transformer work in tandem to increase the overall efficiency that lead to optimisation
solutions of the convex form. These 0,1 solutions have one minimum in their intervals of convexity [13-16]. The semi-toroid symmetry ensures that the determinant of the semi-toroid function is zero. Since a singular matrix is non-invertible, it shows that the semi-toroid has infinitely many optimal solution sets [16].

5. Conclusions
The assessment of several power generation performance characteristics of different solar PV module technologies were compared by simulation in MATLAB. The simulation used five solar modules of different technologies (Monocrystalline, Polycrystalline, Thin films (CdTe, Amorphous and CIGS). A temperature change from 25°C to 50°C, and keeping the irradiance constant at 1000W/m² made the Pmp to decrease by 24.6% and Vmp to decrease by 26.34% for monocrystalline arrays. Also, change in temperature from 25°C to 50°C and keeping the irradiance at 1000W/m² caused the Pmp to decrease by 27.8% and Vmp to decrease by 25.2% for polycrystalline PV arrays. Further change in temperature from 25°C to 50°C and keeping the irradiance at 1000W/m² made the Pmp to decrease by 6.9% and Vmp to decrease by 2.8% for CdTe PV arrays. For the Amorphous PV arrays technology, a change of irradiance from 1000W/m² to 250W/m² and keeping the temperature constant at 25°C caused the Pmp to decrease by 77.7% and Vmp to decrease by 19.0%. A temperature change from 25°C to 50°C and keeping the irradiance at 1000W/m² caused the Pmp to decrease by 20.0% and Vmp to decrease by 28.1%. For the CIGS array technology, a change of irradiance from 1000W/m² to 250W/m² and keeping the temperature constant at 25°C caused the Pmp to decrease by 73.7% and Vmp to increase by 5.2%. Further, a change in temperature from 25°C to 50°C and keeping the irradiance at 1000W/m² caused the Pmp to decrease by 10.0% and Vmp to decrease by 8.7%. The symmetric dome of sun heights against azimuthal angles had 13 fish-like bimodal pyriforms that cut the azimuths at least twice on each of the optimisation lines. Thirteen optimal solution points were visible for every sunlight hour of between 6 and 18 hours (inclusive). These 13 convex sets were global optima (or local optima) with one minimum in the interval of convexity. Also, each of the minimum points for each of the 13 bimodal pyriforms were on azimuth. The monocrystalline PV modules were more efficient at solar energy conversion than polycrystalline and thin film PV modules. The semi-toroid shape provides better efficiency, cheaper, easier and quicker solar PV modules installation, with or without maximum solar tracking system. The proposed semi-toroid solar power tracking system in this paper has infinitely many optimisation solutions, that could competently fit into many diverse applications with rather very stringent performance requirements.

6. References
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