Topic B

Section A: How would you integrate Solar Energy to the Grid (Discuss at least one technical implementation of solar energy to the grid)

Integrating solar energy to the Grid can reduce the dependence on non-renewable energy, generates lesser harmful by-products, and comes with many other benefits. This essay explains the integration of solar energy into the Grid through photovoltaics (PV). Photovoltaics are composed of semiconductor materials, absorbing light energy from the sun and converting them to electrical energy [1].

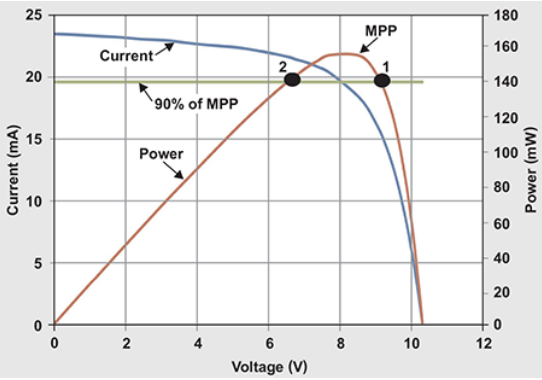

Figure 1. Maximum Power Point (MPP) indicated on an I-V graph

As the sun moves throughout the day (and this movement varies throughout the year with more significant variation at regions further from the equator), solar energy received by the PV cells from the sun changes, causing the power output from the PV cells to vary accordingly [2]. Hence, MPPT (Maximum Power Point Tracking) controls are usually integrated into a PV system to optimise the output from the PV cells. In a PV module, there is a voltage at which the power output is maximum [3]. This point is known as the Maximum Power Point (MPP) and can be obtained from an I-V graph as shown in Figure 1. MPPT algorithms are often incorporated into PV systems to control a DC-DC converter that increase the low DC output from the PC cells and tracks the MPP as much as possible.

Inverters are also instrumental in PV systems. Power generated by PV cells is DC (Direct Current) while the power supply from the Grid is AC (Alternating Current), therefore PV systems typically employ inverters to translate the non-useable DC power from the PV cell to a usable AC power supply that is compatible with the grid [4].

A grid-tied inverter is typically deployed for PV systems that directly connects to the grid [4]. One of its primary responsibilities is to translate DC power supply into AC power supply. This is achieved by switching the direction of the DC input rapidly, often using Field Effect Transistors (FETs) and triacs due to their lower conduction loss in the switch-mode [5].

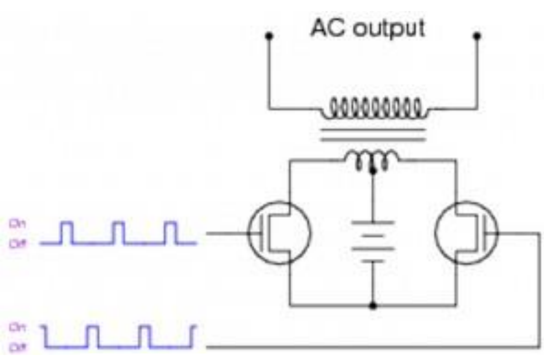

Figure 2. Push pull inverter topology

A simple push pull inverter incorporates a center-tapped transformer (Figure 2) in the circuit to produce two voltages of identical magnitude with opposing polarity, forming an AC output [6]. In this configuration, the transistors are referenced to the ground while the center tap is connected to the positive voltage terminal of the DC output. The centre tapped transformer allows for a more cost-efficient circuit due to the reduced the number of transistors and diodes required [6].

As the output from the transformer is in the square waveform, filters are often deployed to better match the grid's waveform; the more accurately the output waveform matches the grid's waveform, the more efficient the inverter. Pulse Width Modulation (PWM) is used to achieve a pure sine wave output (rather than the less efficient modified sine wave or square wave) [7]. A low pass filter is often used to prevent other harmonic components from reaching the grid while only allowing the fundamental frequency through [8].

Transformerless systems are gaining population due to its smaller size and better mobility compared to its transformer-based counter parts. Transformerless PV systems are also favoured due to the energy loss resulting from transformers [7]. However, transformers provide galvanic isolation and thus, transformerless systems are more susceptible to electrical leakages [7].

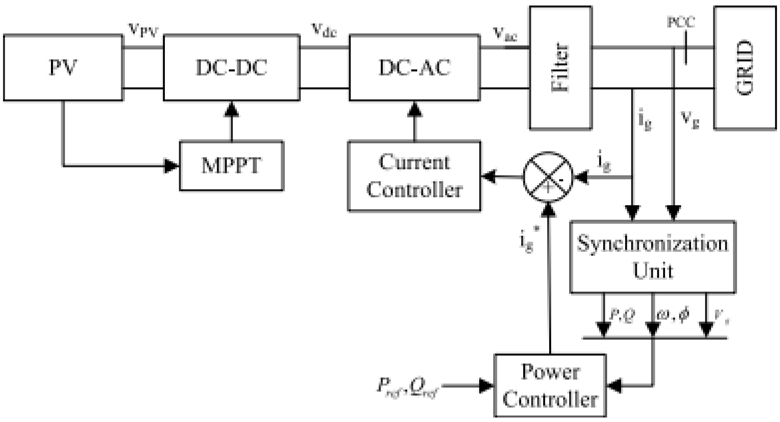

Figure 3. Block diagram of a grid-tied PV system

For grid-tied PV systems, emphasis have been placed into synchronising the PV system output with the grid. A complete block diagram of a typical grid-tied PV system with a closed feedback control mechanism is shown in Figure 3. One common synchronisation method is the Phase Lock Loop (PLL) which is an effective non-linear feedback control mechanism [7].

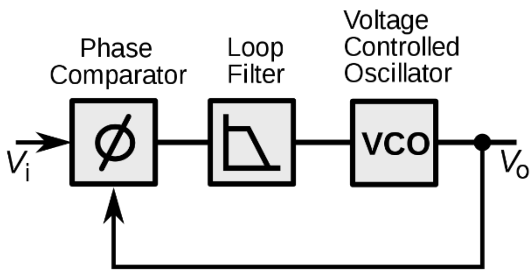

Figure 4. Block diagram of Phase Lock Loop (PLL)

Figure 4 shows the block diagram of a PLL feedback control. The phase comparator measures the phase difference between the grid's voltage and the inverter's output voltage and outputs a voltage value based on this phase difference [9]. The loop is responsible for removing undesired components from the phase comparator and determines the loop stability as well as the transient response of the feedback control [9]. The Voltage Controlled

Oscillator (VCO) is responsible for producing the output based on the filter input from the phase comparator [9].

With all the mentioned components and mechanism in place, the PV system is completed is ready to be integrated into the grid. Moreover, the presented implementations only accounts for a basic and general application, further analysis and finer adjustments should be performed for applications with special circumstances. Other topologies and algorithms should be considered depending on the given environment. It is of paramount importance to check with and obtain the necessary permissions from the relevant authorities before integrating a system onto the grid; in certain regions, transformerless solar inverter might not be allowed due to the associated electrical surges and shocks despite the recognised benefits of a transformerless solar inverter which cannot be disregarded.

Section B: " Do a Feasibility Study for implementing Solar Energy in Singapore".

Aiming to reduce peak emissions by half before 2050 [10], Singapore has made many efforts to introduce renewable energy to its land but are met with many adversaries standing before its ambitious plans. Situated near the equator, Singapore enjoys a high average annual solar irradiance [11], but are undermined by small geography, along with its urban landscape.

Singapore faces inconsistent solar irradiance levels and hence intermittent energy output from PV systems. Inconsistent solar energy levels due to the sun's movement throughout the day and throughout the year (greater effect observed in regions further from the equator) is a common problem not unique to Singapore [2]. Additionally, intermittency problems also arise from high cloud cover due to Singapore's climate [11]. On cloudy and rainy days, the PV panels only generate approximately 10-25 % of their normal capability [12]. Hence, during these days, energy output from PV systems might be insufficient to meet the energy demands.

Having a small land area of about 733 km^2 with high urban activities, land scarcity remains a challenge for Singapore to place PV systems [13]. Urban shading from buildings must also be considered as it contributes to intermittency in PV power output. According to Singapore Energy Market Authority (EMA), 50.8 TWh of energy is consumed in 2020 and thus, a large solar panel surface area is required to meet Singapore's current electricity need [14]. Although land reclamation is being performed to increase Singapore's land area physically, it is an increasingly expensive process and has its own physical limits, thus it is not a feasible long-term solution [15].

To resolve the intermittency drawbacks of solar energy, Singapore have installed energy storage systems to store excess energy produced from the PV systems and distributed for use when the output is lower than the energy demand [16]. Although this provides a more consistent supply of power, this does not address the root cause of the problem where the PV panels are not receiving enough solar energy and the excess energy are insufficient to meet the energy demands. Furthermore, the benefits of these energy storage facilities might not be able to justify the large land area required by them since land is a scarce and valuable resource to Singapore.

Intermittency due to the movement of the sun can be resolved through the installation of solar trackers. Solar tracking system exist on the market that controls and maintain the optimal angle of the PV panel such that it receives the maximum solar energy from the sun [2]. Single axis trackers track the movement of the sun throughout the day while dual axis trackers track the movement of the sun throughout the day and throughout the year [2]. However, as Singapore is near the equator, the changes in movement of the sun throughout the year is insignificant and the cheaper and less complex single axis trackers are sufficient to increase the overall energy output of PV panels and resolve the intermittency problems arising from the movement of the sun without consuming any additional valuable land.

Limited space constraint can be overcome by tapping into viable unused space in Singapore. According to the Singapore Land Authority, approximately 6 km^2 to $8km^2$ of HDB rooftop area can be used for PV installations [17]. By utilising the unused HDB rooftops for PV installations, Singapore high energy demand can be better met. Under the government's SolarNova programme, Housing Development Board (HDB) plans to have a total of 8400 HDB blocks be fitted with solar panels to provide 380 megawatt-peak for the 8400 blocks which is enough to power about 95000 households [18]. However, even if all the HDB roofs are fitted with PV panels, it is still far from meeting Singapore energy requirements. Furthermore, current PV technology requires more PV cells to make up for the low efficiency of about 15 to 21 percent commercially [11]. According to a report by Solar Energy Research Institute of Singapore (SERIS), there is only 37 km^2 of usable space for PV panels. Hence, other spaces must be explored to provide the space for PV installations [11].

Besides HDB, other urban facilities can be explored for PV installations. In 2016, Land Transport Authority (LTA) have plans to install PV panels on two train depots that can generate enough energy to for the depot's operational requirement excluding energy for the trains [19]. Solar roads - roads installed with solar panels, have been tested in other countries, but most of it proved the costly solar roads to be not feasible as they are either not durable enough to tolerate the traffic or produce insignificant amount of energy [20]. However, a 70m bicycle path in Netherlands, installed with solar panels produced promising results due to the generally lighter traffic of bicycles compared to automotive vehicles [21]. The 70m bicycle path produces enough energy to power a small household. This technology can be implemented in Singapore Park Connector Network (PCN) which spans about 300km in total length [22]. By installing PV panels onto current infrastructures, no additional land is wasted, but available urban space for PV installations persists.

Singapore have recognised the limited land constraints and have looked to the water for PV installations. In 2021, Sembcorp Industries have finished the construction of floating solar panel farms in Western Singapore [23]. The solar panel farms can produce 60 megawatt-peak of electricity which is enough to power the 5 water treatment plants [23]. The floating solar panel farms occupy a total area of about 45 football fields and proved to be a viable solution to Singapore's land scarcity as no land area is required for the floating solar panel farms and the surrounding waters serve as a cooling system for the PV systems, providing about 5 to 15% better performance compared to the rooftop PV systems [23].

Installation of floating solar farms requires careful planning and many considerations. Singapore supports a high level of maritime activities and installation of the floating solar farms in the open sea can be detrimental to maritime activities. Furthermore, Singapore boasts a rich marine ecosystem and installation of PV systems should take extra care not to affect the marine ecosystem. Additionally, protection measures must be implemented into the PV systems to counter tidal-waves and unwanted materials such as algae from the water that could wear the system out faster.

The aesthetics and high upfront cost of PV systems might deter developers from installing them. An average household in landed property requires about $20 000 to install a 10kWp PV system [24]. Furthermore, PV systems last for 20-25 years compared to the 40 years life span of a gas-fired power plant [11]. However, the lower maintenance cost of PV systems can cover the higher upfront cost over the lifetime of the PV system [25]. Moreover, excess energy generated from grid-tied PV systems can be sold back to the grid.

Despite the limitations of solar energy in Singapore, it remains one of the most potential renewable sources of energy due to the higher irradiance levels that Singapore receives. As technology improves, efficiency of PV systems is expected to increase while their cost is expected to drop, bridging the gap between solar energy sources and non-renewable energy sources. Despite great potential of solar energy in Singapore, solar energy alone cannot meet the energy demands of Singapore, hence it is instrumental for Singapore to diversify its renewable energy sources into other areas such as wind and hydro energy.

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