Moving Towards Renewables:

How can a smart control system maximize the benefits of a Photovoltaic/Diesel Hybrid System?

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INTRODUCTION

Throughout the world, and particularly in remote regions there is a very high reliance on diesel power to provide electricity needs for domestic and commercial use. Places that are most dependent on diesel powered generation are also often the places paying the highest prices for their diesel fuel due to the remote location and the relatively small quantities being shipped in.

Consequently, it is understandable that there is a strong move towards adopting renewable energy, not just for environmental reasons but also for the economic benefits that a renewable power generation system can provide. However the capital costs of achieving high levels of renewable energy via solar and or wind are massive and the capital funding is not available for high penetration levels. As the move is made towards 100% renewables the costs rise exponentially due to the needs for greater storage.

There is a solution to this problem using a hybrid system which utilises the existing diesel generators, some of them very new, along with a renewable power generation source, usually solar photovoltaics or wind turbines.

The use of a hybrid system cuts the costs of a renewable power generation system dramatically as there is no need to store energy, (which is the largest cost over time), and the biggest outlay (the diesel generator) is generally already in use. All that is required is the renewable source and a smart control system to control the hybrid diesel/renewable system.

WHY USE A HYBRID SYSTEM?

There are several reasons why people start to think about adding renewable energy sources to conventional sources. For example operators of diesel generator sites have very high OPEX (due to immense diesel consumption if the sets run 24/7), they are under pressure due to high amount of emissions produced, and they also start to realize the threat of being dependent on a single fuel supply.

A photovoltaic (PV) system on its own is now cheaper than diesel in most parts of the world (assuming that it is not a country where fuel prices are massively subsidized). Therefore, it makes simple economic sense to add PV to a diesel installation and start saving money immediately. The main barrier is normally capital cost; however, it is a simple matter to start off with a small amount of PV and add to it in stages using the savings that are already being made.

So, the two prerequisites making a site run on a hybrid system are the following - the prime power is generated from diesel gen-set(s) and the location offers good conditions for photovoltaics or wind turbines.

THE THREE HYBRID ESSENTIALS

To achieve a highly successful, reliable and efficient hybrid control system there are three essential requirements that must be met:

1. The amount of energy generated by the renewables must be maximized.

Whilst the ‘fuel’ is free with PV and wind, the capital costs are enormous when compared with traditional diesel generation. Currently the cost of large-scale PV generation plant (multi MW) is about 3.00 USD/W, whereas a diesel power station is about 0.80 USD/W. In addition to this additional capital cost is the fact that PV can only work during daylight hours, while wind is even less reliable – only being available during certain wind levels, (and having the system shut down if the wind level gets too high).

Consequently it is absolutely essential that every possible kW available from renewable sources be utilized so that the return on the capital cost is maximized. For optimum utilization of PV it is crucial to correctly size the PV. If it is too small, the ROI period might be too long, but if it is too big, it will put additional requirements on the control system and might involve installation of batteries to store excess power.

2. The reliability of the existing system must not be compromised

The level of reliability with large-scale diesel generation is very high and many systems will go for a decade or more without a single outage. For many operations, this high level of reliability is essential – e.g. a sudden loss of power for a mine can be catastrophic. Consequently, it is essential that a hybrid system maintain this very high level of reliability. Nothing will do more to put people off a hybrid system than if they must put up with higher levels of faults and blackouts.

3. The remaining diesel portion must continue to have the same level of efficiency as the existing operation.

If the diesel part of the hybrid system runs less efficiently after the hybrid installation, then the money saved by having ‘free’ renewable energy is going to be used in supplying diesel to the generator. So, it is essential that the diesel portion of the power generation system be run in a manner that optimizes operating efficiently in the face of sometimes rapidly varying levels of load.

To meet these three requirements, it is essential to know the load profile, design the size of different power generation sources appropriately, and have a sophisticated and smart hybrid control system.

THE HYBRID DECISION

Achieving a successful hybrid installation is a trade-off between having a sufficient return on investment, and the diesel savings made against the very high capital cost. As you try to get close to 100% penetration the cost curve becomes exponential due to the increasing amounts of storage required. (For example at close to 100% renewables penetration you need to have three times the amount of PV compared with the average load, plus an extra amount for cloudy/non-windy days, and be able to store the average load for a minimum of 16 hours to provide power supply overnight – this obviously comes at massive cost).

Whilst the figures will vary slightly depending on location, (cost of fuel, technology used, etc.) in general there is a 'sweet spot' between 20% and 60% penetration that makes economic sense in most situations, as depicted on the graph below.

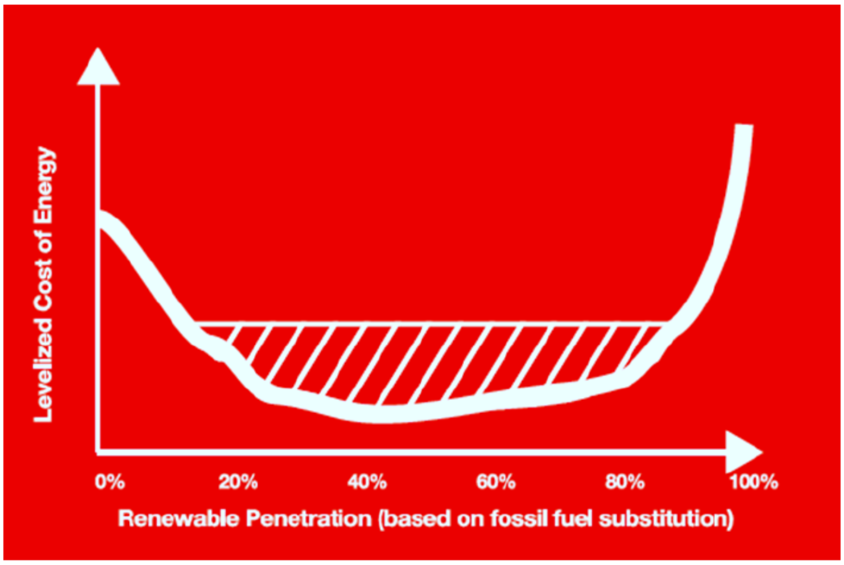

Image 6.1 Graph Levelized cost of energy vs. Renewable energy penetration

LESS THAN 30% PENETRATION

If the installed capacity in renewable energy source is less than 30% of the installed capacity in the diesel gen-sets (or if the renewables covers not more than 30% of the consumption), then the overall control of the system is relatively easy, the system reliability is high because at least one gen-set is always running and the investment into PV technology is not as significant; (a battery is not required). However, since the renewable contribution is lower, so are the outcomes, such as OPEX and CO_2 reduction, and the renewable output can need to be curtailed to avoid underloading of the gen-set.

- Positives
  - Easy control
  - High reliability

    - Low CAPEX
- Negatives
    - Limited reduction of OPEX (High OPEX)
    - Low reduction of CO_2
    - RE output limitation

This low penetration is suitable mainly for sites with highly variable loads.

30 - 60% PENETRATION

If the installed capacity in renewable energy source is higher, but still less than 60% of the installed capacity in the diesel gen-sets (or if the renewables covers no more than 60% of the consumption), the overall control is more complex, as energy storage might be involved to cover potential mismatch between the renewable generation and overall power consumption. The storage should also ensure that renewable utilization is maximized and therefore operation of the gen-set is minimized. In such a case the OPEX is reduced more significantly, however CAPEX due to the energy storage (batteries) is notably higher.

- Positives
    - Lower OPEX
    - Maximized RE output utilization
    - Minimized gen-set operation
- Negatives
    - Higher CAPEX
    - Lower reliability

In most cases where grid tied PV inverters are used, it is essential to keep one gen-set running at-all-times to provide the voltage and frequency reference. However, even where standalone inverters are used, it is best practice to keep a generator running at-all-times. System reliability should not be compromised, so there should be still at least one gen-set running as a backup power supply if something goes wrong. The master controller in this case prevents the gen-set from underloading by minimizing the PV. However, such an operation does not lead to maximum OPEX reduction. The gen-set can be stopped if there is battery storage designed to cover short power supply cuts during which the gen-set can be started and take over the load. For such operations high speed gen-sets are recommended.

60 - 100% PENETRATION

Systems with renewables penetration up to 100% minimize gen-set operation and thus the OPEX on diesel and prolong the maintenance intervals, whilst maximizing the renewables output. However, energy storage, which is inevitable in such systems, increases significantly the CAPEX and thus prolongs the return on investment period. Maintaining reliability of the system puts high demands on the control system.

- Positives
  - Very low OPEX
  - Maximized renewables output utilization
  - Minimized gen-set operation
- Negatives
  - Very high CAPEX
  - Lower reliability
  - High demands on control system

Higher penetration (up to 100%) is relatively demanding on the overall system stability and is therefore suitable mainly for sites with stable day load and favourable PV conditions.

SUITABLE APPLICATION OF A HYBRID SYSTEM

MINING

Mines are commonly located in remote areas and are often dependent on locally generated power using diesel engines. The power levels are normally high and range up to 40MW (Typically above this level they often use gas turbines).

REMOTE TOWNS, ISLANDS AND COMMUNITIES

Whilst in Europe and the US almost every small town and village is connected to a major grid this is not true in many parts of the world including Africa, South America, Asia and the Pacific Islands. In these areas, many small towns and islands each have their own diesel power station and their remote location means that the cost of diesel is much higher.

REMOTE RESORTS AND TOURIST FACILITIES

A current trend in tourism is 'ecological tourism' and that often means remote locations, and therefore the resorts and tourist attractions must supply their own electricity. However, because they are often promoted as 'environmentally friendly' they have a greater need than most to reduce their reliance on diesel power and are therefore ideal targets for a hybrid system because they normally cannot afford the massive costs of going to 100% renewable energy.

REMOTE MANUFACTURING FACILITIES

Whilst most industry is concentrated in towns and big cities, there are several manufacturing operations around the world that are located away from these areas. The most common examples are related to agricultural processing where it is too expensive to transport all the produce to a processing or manufacturing plant so it is done where the item is grown.

AGRICULTURAL SITES

Large agricultural sites can have very high energy consumption due to irrigation systems which water large production fields. Due to their high power consumption, they are often off-grid and producing their own power. Such sites can also take the advantage of biogas availability and use biogas gen-sets for the base load.

MILITARY

Often the military must take its power with it, as it is not normally operating in an area where it has access to the grid power system. Consequently, they are huge users of diesel gen-sets but because of the logistical and financial costs involved many countries military organizations are already investigating in hybrid systems for their power generation needs.

Military training camps are also often located in remote areas, or have load demands that have their own generating sets, and are therefore looking for alternatives how to lower their operating costs.

RENTAL

There is significant potential in rental gen-sets as the rental companies are one of the largest owners of gen-sets. But, because of the set-up and strip down costs for PV it is not viable for them to offer a hybrid system for their short-term rentals. However, many of their major contracts for large construction projects or for mining operations are often for many years and in these cases, it would be economical to offer a hybrid system which would give them a sales advantage when tendering.

LOCATIONS WITH UNRELIABLE GRID SUPPLY (STANDBY SETS)

There are many parts of the world where, although most premises are connected to a grid, the power supply is unreliable, and therefore standby sets often run eight or more hours per day. As a market, we can treat these installations as base load also and as many of them are factories they have large roof areas for the location of PV panels.

OTHER APPLICATIONS

All the above mentioned applications have something in common - they are in remote locations where the main grid is difficult to access or the power supply is unrealiable

There are also two other types of applications that can be on-grid with reliable power supply, but where installation of PV plays a significant role in OPEX reduction:

- Commercial sites where a backup diesel gen-set is used in demand side management (zero export)
- Commercial sites where a backup diesel gen-set is used for peak-lopping (power supply to the grid as a regulation energy)

WHAT CAN WE ACHIEVE WITH A "SMART" CONTROL SYSTEM?

The competing demands of a hybrid system require a high level of sophistication in the control system. To meet the three requirements discussed earlier, plus the need to minimize the amount of storage, there are several solutions that our experience in the industry allows us to use.

High speed/low speed

Where there is a mixture of both high speed and low speed gen-sets on a site, it can be beneficial to adjust the two types in a couple of ways. Firstly, the slow-speed sets will often be older than the high-speed sets and therefore will have a steeper fuel consumption curve; (i.e. the fuel consumed per kW generated will rise very fast. It is a good idea to use power management to set up the system so that most of the time the slow speed sets run at a fixed base load to optimise fuel consumption and the high-speed sets take up all the variation in load as high-speed engines have a much flatter fuel consumption curve.

Secondly, slow-speed sets have much longer starting times than high-speeds sets due to the necessity to pre-lube etc. Therefore. in a hybrid situation it can be beneficial to have the slow speed sets running and keep at least one high speed set in reserve for fast start-up when the PV suddenly drops due to a change in weather. High-speed sets can normally be on line and accepting load within 15 seconds whereas a slow-speed set can be as-long-as 10 minutes. Many of the issues with the starting of slow speed sets can be dealt with and if the control system is being modified as part of the hybrid installation.

Overload capacity

The overload capacity of modern gen-sets is often overlooked – operators only look at the rating of the sets. However, every set has an overload capacity that is stated by the manufacturer. This is a minimum of 10% and on many sets, is much more. The difference between the base load rating and the standby rating on gen-sets can be as high as 25%. This overload capacity can be utilized for the short time that it takes to get another set online.

UPGRADING EXISTING SYSTEMS

However, clear majority of hybrid installations over the next ten years will be the addition of renewables to existing gen-set installations. In such cases, it will be necessary to upgrade the existing control system. In many instances the system will be manually controlled and operated and it is important that the existing station is automated. Changes happen very fast in a hybrid installation, for example; if a cloud comes over the PV array, the output can drop from maximum to almost zero in as little as a few seconds. No human operator can react this fast; nor can he continuously calculate the amount of spinning reserve needed as the amount of wind energy or PV constantly changes.

POWER STORAGE

Higher renewable penetration requires energy storage within the system to allow the shutdown of an unloaded gen-set in the background, ready to cover power supply shortages during drops of PV output. It also allows maximum PV penetration. However, energy storage has still not reached its optimum level of efficiency and since the technology development is still in progress, storage is still very expensive and makes hybrid system investment significantly costly.

Research and development of energy storage technology has been on an uptake within the last few decades as they have started to be massively used in wide range of applications. There are various types of energy storage that can be seen in hybrid applications, mainly used for supplying power immediately after the output from a renewable is lost and before a gen-set is started. Even though the main idea behind a hybrid system is to lower the burden of diesel emissions and utilizing green renewable energy instead, to achieve 100% renewables penetration, there is a need to use some sort of energy storage. Below are listed few of the most typically used technologies.

UPS

An uninterruptible power source (UPS) must step in when a main power source is lost. It must instantaneously start to supply power from energy storage, either a battery or a flywheel, to cover the load before a standby power source is started. UPS are used in number of applications, hybrids being one of them.

BATTERIES

There are various types of batteries, differing in the materials used for the electrodes and electrolyte; nevertheless, the most widespread are Lead-Acid and Lithium-Ion.

In general, Lead-Acid is the oldest technology, having very low energy-to-weight ratio, but the ability to provide high currents means that they have high power-to-weight ratio. They are relatively cheap; providing the best value for power and energy per kWh in their price range and have the longest life cycle if maintained correctly. However, they do not like deep discharge and due to limited number of charge/discharge cycles, they are not suitable for applications where regular discharge is required. They are also very susceptible to changes in ambient temperature and because of the chemicals used, are environmentally unfriendly.

Li-Ion have highly differing life cycle depending on the depth they are discharged. They allow 70% depth of discharge; however, this shortens the battery life cycle. If discharged only by 10%, the lifecycle can be up to 30 times longer. Their advantage is the energy-to-weight ratio, but they are more expensive than Lead-Acid batteries and recycling process is not yet established.

FLYWHEELS

Flywheel, or a rotor, is accelerated to a very high speed, maintaining the rotational energy with very low frictional losses in its center and converting the spinning energy to electrical energy when the main source of power is down. By using some of the rotational energy, the flywheel rotational speed is reduced and it is ready to capture energy from intermittent sources and use it for load supply when needed.

Other advantages of a flywheel are low maintenance, long life and higher energy density, nevertheless all the advantages are balanced by a high price.

THE ISSUE OF LIGHT LOADING

One of the concerns related to hybrid system implementation is with regards to gen-set light loading, or underloading. To avoid power supply shortage when renewable output suddenly drops, sufficient spinning reserve should be kept on the gen-set to cover such fluctuations, which means that at times the sets might be running under a light load. Operators and owners of gen-sets are concerned about light loading because they have heard that it can cause all sorts of problems – particularly glazing of the bores. However, these sorts of problems do not occur with just a few hours of light loading – it takes weeks or even months at the same light load before it occurs.

In a hybrid installation, there is a higher chance of light loading the generator because of the availability of the renewable source. If it is constantly sunny or windy, the generator’s load will be quite low, but with a smart system, the amount of energy provided by the renewable source can be adjusted to ensure that the generator is running at optimum efficiency.

EXAMPLES OF OPERATIONAL HYBRID SYSTEMS

Peter Island, British Virgin Islands.

Popular honeymoon destination Peter Island in the British Virgin Islands has recently seen an upgrade of the island power generation control system leading to more efficient automatic control of the four diesel gen-sets along with the wind turbine operation. Completion of the project laid a necessary grounding for future photovoltaic installation.

This project was divided to two phases, during Phase 1 ComAp retrofitted the existing diesel gen-set control system to allow for automatic control of the gen-sets operation to supply the load along with the wind turbines. The main objective was to lower the load reserve by optimizing the power management. Thanks to the fact that ComAp's control system allows for stabilized operation of only one gen-set on a bus, the fuel consumption costs should be cut by $500,000 per a year.

Phase 1 was completed within 13 days without single interruption of the power supply and established solid base for Phase 2. The objective of Phase 2 was to ensure smooth operation of the gen-sets along with the wind turbines, offering the option of curtailing the wind turbine output in high wind speed occurrence, and lay a grounding for the site future extension by adding PV.

The project will provide number of benefits to the Peter Island, to name a few, it will ensure

- data analysis regarding the output values of all components
- highly efficient power supply from combination of the two sources of energy
- optimized fuel consumption with reduced diesel fuel emissions
- prevention of the wind turbine damage by its power output limitation when necessary
- prevention of the gen-sets from underloading

Rottnest Island, Western Australia.

A popular tourist destination in Western Australia; Rottnest Island has recently seen the initiation of a large-scale hybrid project, which was completed in March 2017. The project combines renewable energy and smart controls to reduce the amount of diesel fuel required to produce clean drinking water and generate power for the remote island.

In this high-profile project, ComAp was commissioned to upgrade the existing diesel power station at Rottnest Island to enable it to seamlessly integrate with Hydro Tasmania's hybrid power system controller. This was to allow for wind turbines, photovoltaic and water storage integration.
ComAp engineered a solution to transition the existing diesel engines and 11kV feeders to a new unit control platform, enabling real-time communication and control via its diesel

station controller. Hydro Tasmania's hybrid power system controller interfaces directly with the ComAp system and manages the wind, solar, water storage facility and desalination plant and combination with its dynamically controlled resistor to manage excess spill energy.

This project will provide several benefits for Rottnest Island by enabling the power station to
integrate with wind, solar and demand-side management of the desalination plant in a bid to
have cleaner energy.

With the addition of fully automated black start capabilities and the optimisation to enhance the wind and renewable energy penetration, the power station is expected to reduce diesel fuel usage for power generation by 45%, as well as significantly reduce operational costs and diesel fuel emissions.

Tarawa, Kiribati

The Republic of Kiribati is an island nation in the Pacific Ocean. Tarawa, one of Kiribati's 33 atolls is home to more than 50,000 inhabitants and, as with most of the islands in the Pacific, it originally used diesel generators to generate 100% of its electricity.

To reduce the dependency on diesel imports a 500 kWp photovoltaic power plant was built on the island, to be integrated into the Public Utilities Board's electrical grid.

This required full automation of the existing three 1400 kW low speed diesel generator systems. Originally the control system was predominately hardwired utilizing relay logic, timers and operator hand switches to manually operate the plant. This setup would not be able to react on constantly changing power output from the PV plant so ComAp has installed a fully automatic system using InteliSysNT-BaseBox controllers with special hybrid firmware.

This solution has been integrated into Hybrid Wizard, a patented global hybrid control system – developed by French company Vergnet S.A, which improves the overall network stability and robustness and allowed smooth integration of the PV plant. Today the PV plant covers around 10% of Tarawa's electricity consumption but the plan is to increase this number by installing more PV in the future.

The hybrid system saves approximately 227,000 litres of diesel every year and prevents around 627 tons of CO2 from being released into the atmosphere.

CONCLUSION

There is a strong move towards adopting renewable energy, not just for environmental reasons but also for the economic benefits that a renewable power generation system can provide. A hybrid installation, with by a smart control system, (such as the one detailed in the examples, and installed by ComAp), is the perfect solution for balancing the needs of a reliable power supply with the environmental and cost saving benefits of a renewable source of energy. A hybrid systems ensures the perfect ration of benefitting environment, cost savings for the customer and reliable power needs, all in the same application.