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White Paper

# Solar-Diesel Integration: The Right Way

Safe and economic integration of photovoltaic systems with existing diesel generators.

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## Safe and economic integration of photovoltaic systems with existing diesel generators.

## Abstract

Diesel generators are heavily relied upon wherever grid power supply is unreliable or non-existent. And such generators may continue to dominate until energy storage comes of age. Fortunately, solar photovoltaic systems are finding a strong foothold in abating diesel consumption. However, if integrated incorrectly, one might not see much of a financial (or environmental) benefit, or even worse, the photovoltaic system can end up causing irreversible damage to the diesel generators and bring down the entire power system. This white paper describes the most appropriate way of integrating photovoltaic systems with existing diesel generators.

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## Why integrate PV with Diesel Generators?

Several technical specifications for solar photovoltaic (PV) systems recently have started mentioning the term 'integration with diesel generators'. The objectives for integration are simple:

1. Savings: Minimize the usage of diesel by giving priority of energy generation to the PV system, and

2. Protection: Protect the diesel generator against 'back-feeding' of PV-generated electricity into the generator.

Unfortunately, different PV system suppliers interpret the term 'integration' differently. Let's consider a general case of wiring topology of a campus that uses diesel generators to discuss what should be done, and more importantly, what should be avoided.

We will refer to a case of a campus, the electrical layout schematic of which is shown in Figure 1. This campus has two numbers of 50 kVA diesel generators. Note that the incoming power from the grid is first distributed into 'critical' and 'non-critical' supply. The output power of the two diesel generators is synchronized through an 'auto synchronization panel'. In the given case, the total connected critical load is 100 kW. The 'auto changeover panel' works as a selector switch; it routes the grid supply to critical loads, and in the event of grid failure, will disconnect from the grid and route power from the diesel generators to the critical loads.

Further, let us assume that we are able to install two independent systems of 20 kW and 30 kW at two locations within the campus. The question now is…

## Where do I interconnect the PV systems?

OPTION 1: The most common and an inappropriate shortcut is to interconnect the PV systems to the circuit consisting of non-critical loads, which as per Figure 1 would be anywhere along feeders (d), (e) or (f). In case of grid failure, this non-critical circuit would also be de-energized, and will cause the PV systems to go into a stand-by mode. The diesel generators would end up catering to the critical loads, and in spite of the PV system being present, they will not contribute to any saving in diesel usage.

Hence, Option 1 classifies as 'inefficient'.

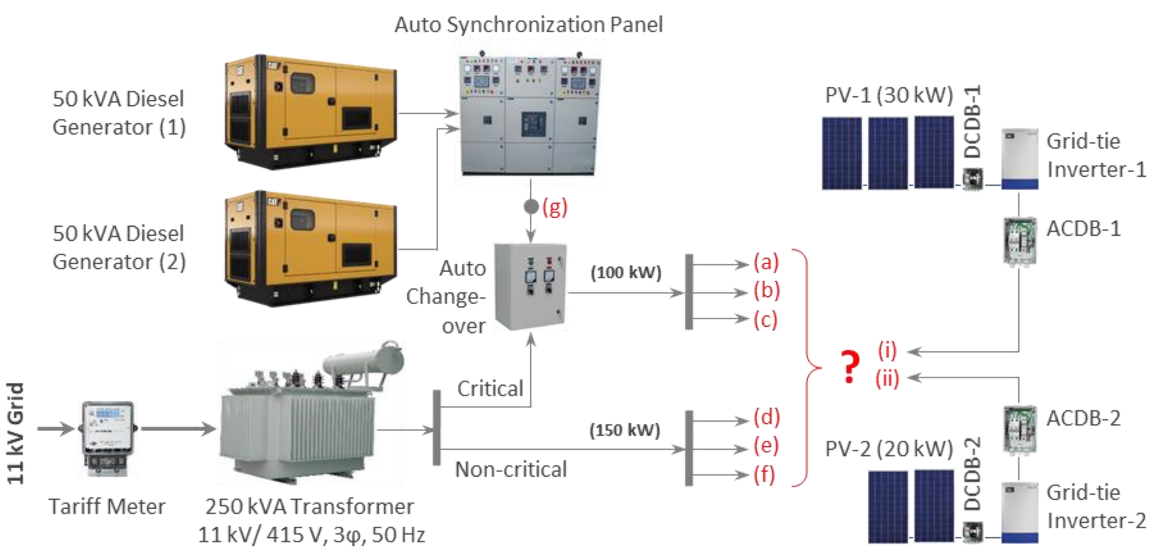


*Figure 1: A typical wiring topology consisting of diesel generators.*

OPTION 2: Realizing the disadvantages of Option 1, a second option would be to interconnect the PV systems to the circuit consisting of critical loads, which as per Figure 1, would be anywhere along feeders (a), (b) or (c). In this case, the electricity generated from the PV systems would first be used by the critical loads, and the remaining electricity would fed to the non-critical loads or the grid. In case of grid failure, the diesel generators would continue to supply power to the critical load keeping the critical feeders live, which in turn would enable smooth operation of the PV systems.

However, this works well only until the critical load is greater than the power generated by the PV systems. In case the critical load drops to less than the power generated by the PV systems, the surplus electricity generated by the PV system would be pushed into the diesel generator, which could potentially damage the diesel generator.

Hence, Option 2 classifies as 'dangerous'. This option should be avoided even if the capacity of the PV system is substantially less than the critical load.

OPTION 2.1: In order to avoid back-feeding of solar power into the diesel generator as described in Option 2, it is observed that several installers install a 'unidirectional relay' at point (g) shown in Figure 1. This will, for sure, protect the diesel generators against any back-feeding of electricity from the PV systems.

However, in the event that the critical load becomes less than the power generated by the PV systems, the unidirectional relay would trip 'open' and as a result, electricity from the diesel generators would cease from powering the critical circuits. This would cause a chain reaction, where then PV systems would start entering stand-by mode due to lack of reference voltage at their interconnection points (which was coming from the diesel generators).

Once the PV systems would go offline, the diesel generators would start powering the critical loads again, but would also cause the PV systems to come online again; and once again, cause the unidirectional relay to trip open. This vicious 'on-off cycle' would continue till the time when the PV systems' output power drops below the critical load consumption or the critical load consumption increases to more than the PV systems' output.

Hence, Option 2.1 classifies as 'inconvenient and annoying'.

OPTION 3: The feeding-in of solar power into the diesel generators described in Option 2 can be avoided by ensuring that, at the time of grid failure when the diesel generators are

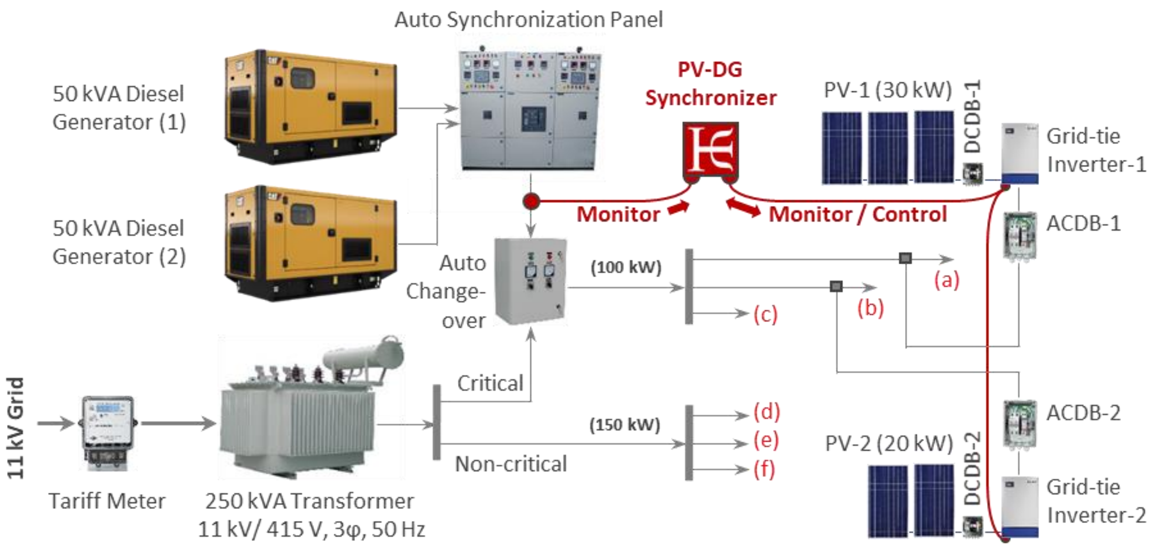


*Figure 2: Interconnection for a sophisticated solar-diesel generator synchronization 'solution'.*

functional, the output power from PV systems is always less than the critical load. This way, there will always be some power output from the diesel generators, which will ensure its safe and healthy operation.

A sophisticated solar-diesel generator synchronization 'solution' will monitor the output of the diesel generator and also control the PV inverters at interface points shown in Figure 2. Typically, the user is allowed to set a minimum threshold for the power output of the diesel generators. If the actual power output from the diesel generators falls below this threshold, then the solution starts 'backing down' the PV inverters to ensure that the minimum output threshold of the diesel generators is maintained.

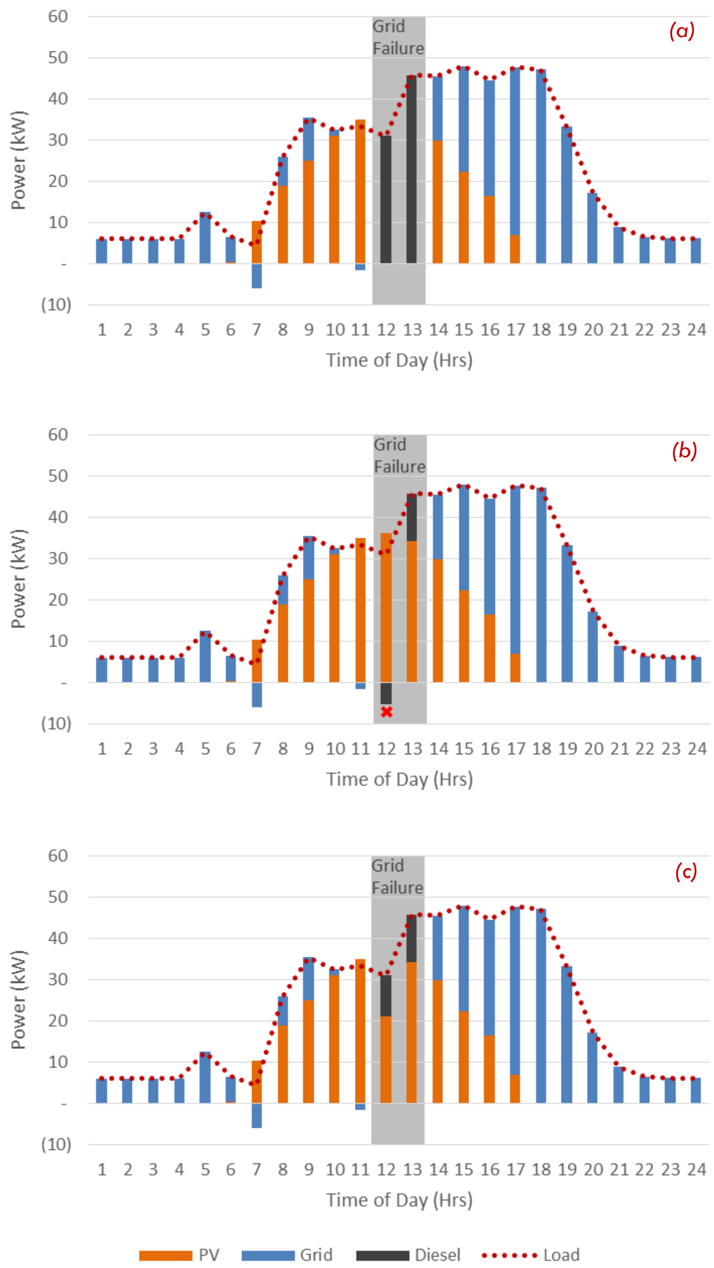


*Figure 3: Power generation combination under discussed options.*

Figure 3 shows how the combination of diesel generators and the PV systems meet the power requirement of the campus under the various options discussed above. The under-utilization of a PV system connected to a non-critical feeder, which is not connected to a diesel generator, is seen in 'Case 1'. Here, the PV systems go on stand-by during 12 noon and 1 pm, when the gird is down, and a diesel generator is completely supplying power during this time. 'Case 2' highlights the dangers of evacuating PV power in a critical feeder without appropriate inverter control. It can be seen that, at 12 noon, the surplus PV power is back-fed into a diesel generator.

In can be seen in 'Case 3', that at 12 noon and 1 pm, there is a certain minimum amount of power being supplied by the diesel generator. Here, the synchronization solution is backing down the PV generation so that the diesel generator is supplying at least 20% of its capacity (i.e. 10 kVA). Thus, the diesel power generation minimized, but does not drop below its critical threshold.

## How much money am I saving?

Monetary savings are calculated based on the following levelized cost of electricity (LCOE):

## Does the diesel generator have a fuel governor?

When a diesel generator is not producing power at its maximum capacity, we usually expect it to consume diesel at a proportionally lower rate. However, does the diesel generator really lower its fuel consumption when not running on full capacity? The answer lies on whether the diesel generator has a fuel governor or not. A fuel governor restricts the flow of diesel into the generator to a level partially corresponding to its load. Figure 4 shows the relation of the fuel consumption (and efficiency) of a 100 kVA diesel generator with its load. While most of diesel generators today have a fuel governor, many of the older models don't. Such older generators can also be retrofitted with fuel governors to increase their efficiency. As for purchasing new diesel generators, it is always helpful to ascertain the inclusion of a fuel governor during the purchase.

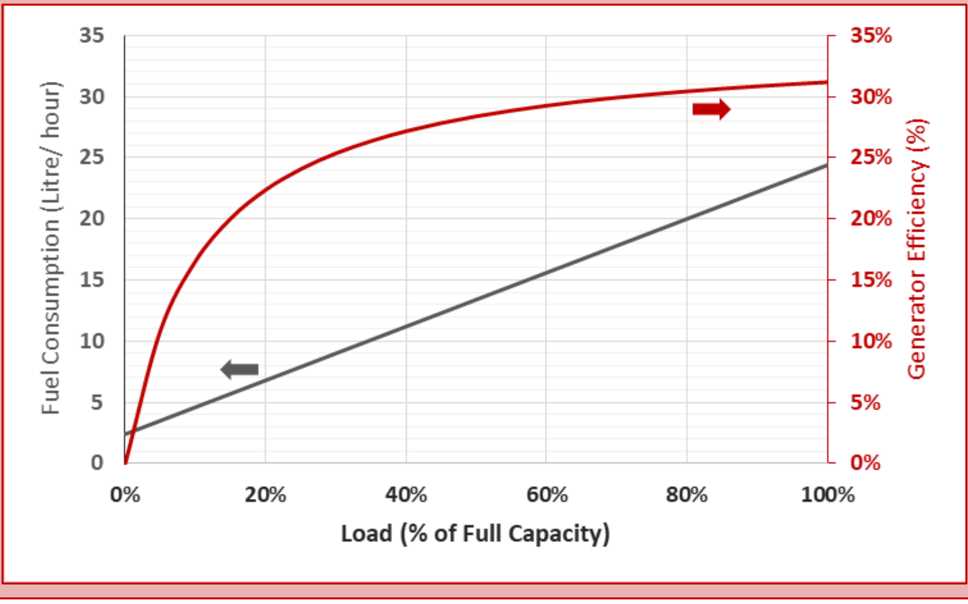


*Table 1: LCOE based on different sources.*

| Source | | LCOE |
|---|---|---|
| Grid | : | Rs. 8.00 /kWh |
| Diesel Generator | : | Rs. 15.00 /kWh |
| Photovoltaic System | : | Rs. 4.00 /kWh |

We calculate the overall LCOE based on the energy usage and outages shown in Figure 3. For the case where there are no PV systems, the consumer's LCOE is based on the weighted average of grid and diesel-generated electricity, and is computed as Rs. 8.96 /kWh. The LCOE for various options discussed in this paper are summarized in Table 2.

Hence, a solar-diesel generator synchronization 'solution' (Option 3) is the correct option to interconnect a PV system where diesel generators are being used. Such a solution yields an optimized financial (and environmental) economy, and does not flout any norms of safety.

*Table 2: LCOE computed for various options.*

| Option | | LCOE | Safe? |
|---|---|---|---|
| Without PV (Baseline: Grid + Diesel) | : | Rs. 8.96 /kWh | Yes |
| Option 1 (PV connected to non-critical circuit) | : | Rs. 7.56 /kWh | Yes |
| Option 2 (PV connected to critical circuit, but without 'back-down' function) | : | Rs. 6.18 /kWh | No |
| Option 3(PV connected to critical circuit, with solar-diesel generator synchronization 'solution') | : | Rs. 6.48 /kWh | Yes |

# Notes