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A technical model for optimising PV-diesel-battery hybrid power systems

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INTRODUCTION

Decentralised power generation systems based on renewable energy can play an important role in hastening the arrival of electricity to many remote rural areas of Southern Africa. The hybrid energy generation concept has many comparative advantages over single-source generation, and a PV-diesel-battery system is a particularly attractive option for decentralised power supply in Southern Africa where solar radiation is ubiquitous in most countries. This paper presents the development and application of a simple spreadsheet-based simulation model for sizing and performance evaluation of PV-diesel-battery power supply systems. The model is able to generate a set of sizing curves that define the design space for hybrid systems using dimensionless component size variables, for a specified supply reliability and diesel energy dispatch strategy.

PV-DIESEL-BATTERY HYBRID SYSTEM AND ENERGY FLOW LOGIC

Electrical energy generated by the solar PV array and the diesel generator (DG) can either be consumed by the load, supplied to the battery, or wasted (dumped energy), depending on the instantaneous magnitude of the load and state of charge of the storage battery.

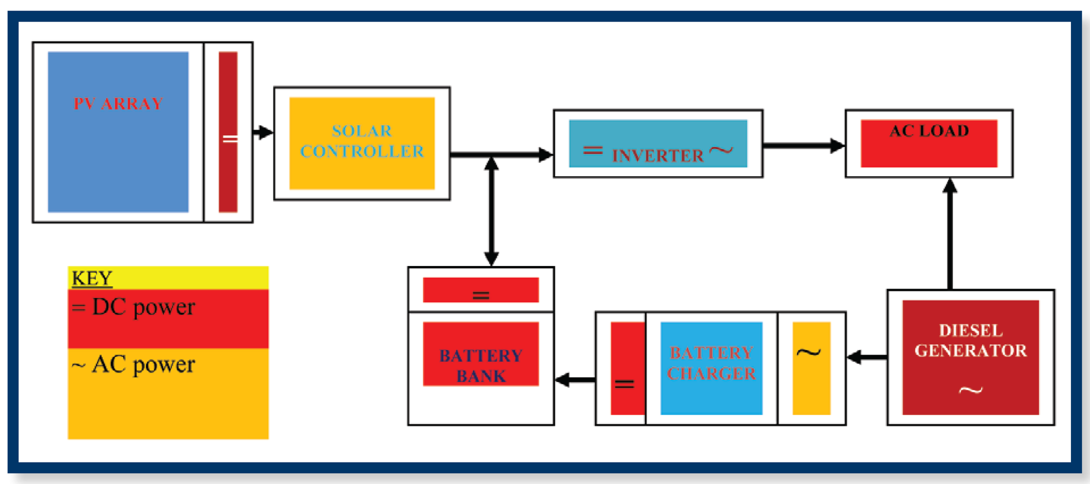

Figure 1: Schematic representation of a typical PV-diesel-battery hybrid power supply system

For any given hour, the DG output is either zero or the rated DG power, depending on whether the DG is switched off or on, respectively, for the hour in question. The conditions for switching on or off depend on the DG energy dispatch strategy adopted by the system designers and/or operators. In the present study, two different dispatch strategies are analysed.

(1) The night dispatch strategy assumes that the DG will be switched on only at night (when there is no solar radiation).

(2) In the load-following strategy the DG is switched on when the load equals or exceeds a certain prescribed threshold

In the model, the load can take any value in the following categories resulting in a different energy flow logic for each load category:

If the hourly-average energy demand is less than the rated power output of the diesel generator, the DG can more than satisfy the load on its own; and the excess energy goes to charging the battery. The excess DG energy, over that supplied to the load and accepted by the battery, goes to waste. In this load category, the available PV energy goes to charging the battery, provided that it is not already fully charged by previous charge events, with the excess PV energy also going to waste.

If the hourly-average energy demand is greater than or equal to the total of the rated DG output and PV array output (system output), the load can be satisfied by the combined output of the DG and the PV array. All of the DG output is consumed by the load with the deficit, if any, supplied by the PV array through the inverter. The excess PV energy (over that supplied to the inverter) goes to the battery and/or to waste; the amounts going either way depending on the state of charge of the battery relative to the available excess energy.

Finally, if the hourly-average energy demand is greater than the system output, the combined output of the DG and the PV array is not enough to satisfy the load, hence there is no energy dumped. The energy deficit is provided by the battery, which can discharge energy only when its depth of discharge is less than the maximum allowed. It is possible under this load category for the combined hourly output of the battery, PV array and DG to fall short of the hourly load. The system is defined to experience "loss of load" under these circumstances. At this point the system controller will intentionally disconnect the load from the battery, thereby avoiding a severe discharge that could damage the battery.

SYSTEM SIZING

The procedure used is to define the hybrid system design space by generating a family of system sizing curves then plot PV array size required to attain a prescribed level of supply reliability, against battery size, for different values of DG size. The DG size is characterised by the normalised variable, rated DG output over the daily average load, Q_{DG}/d; and the battery size is represented by the variable, battery capacity over daily electrical load, B_{cap}/D.

An Excel spreadsheet calculator was developed for computing, among other things, the loss of load fraction (LLF) from inputs of the three variables, normalised array area, battery capacity and diesel generator size; as well as inputs defining the diesel generator dispatch strategy. The LLF is defined here as the fraction of annual hours when the power supply system fails to completely satisfy the load. For a chosen dispatch strategy, each sizing curve is generated by fixing the DG size; and the combinations of battery capacity and array area that just yield the prescribed LLF are the required coordinates of the sizing curve.

The following can be observed from the sizing curves. The PV array area required to achieve a chosen level of reliability decreases with increase in the battery size (along each sizing curve), and with increase in DG size (among different sizing curves). Greater supply reliability (decreased LLF) of course calls for larger sizes of the hybrid system components and a correspondingly larger system cost. The prescribed system component size combinations differ from one DG dispatch strategy to the other.

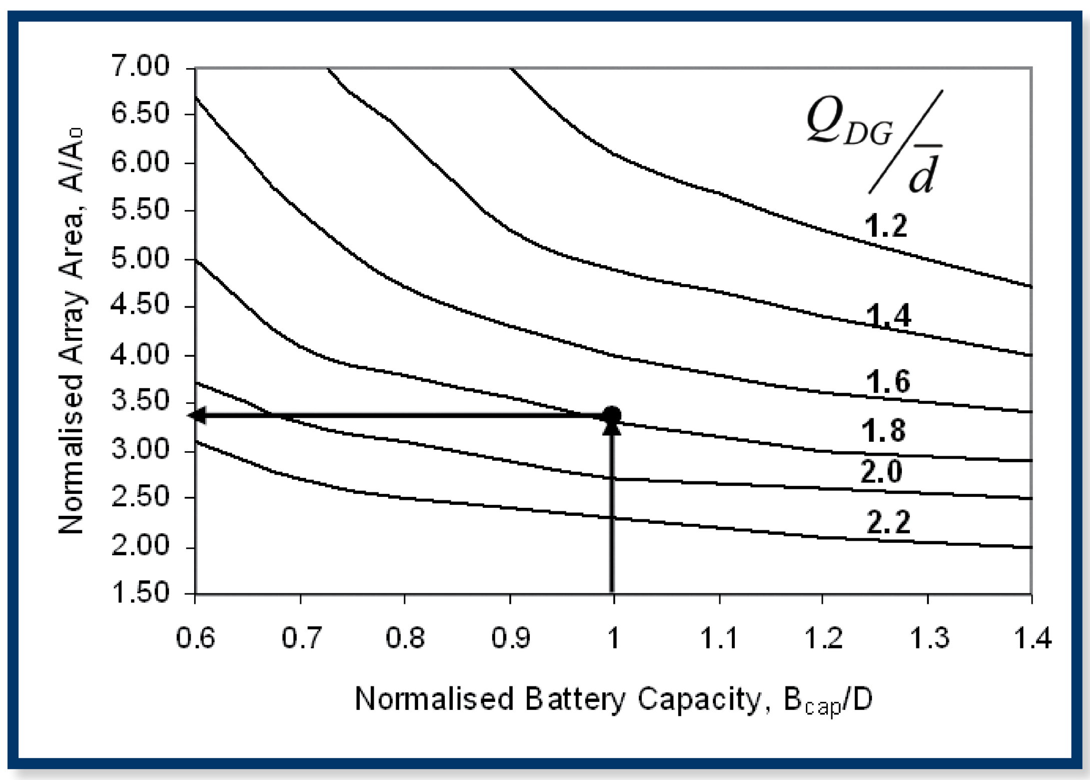

Figure 2: Sizing curves for system on load-following dispatch strategy.

Once constructed, the sizing curve can be used as a design tool for the system. First, they can be used to determine all possible combinations of component size variables, normalised array area, battery capacity and DG size, that satisfies a given load and diurnal profile to a desired degree of reliability. The compliant size combinations can then be subjected to optimisation scrutiny to select the optimum combination. Second, given any two of the size variables, one can fix the third variable. The actual values are calculated in the model via given equations.

RESULTS AND CONCLUSION

The model was used to compute the energy performance of systems with different combinations of component sizes, for two different DG dispatch strategies (load-following and night dispatch strategies).

The importance of DG energy dispatch strategy in influencing optimal-system component sizing and operational parameters is well illustrated. Comparing the two hybrid PV-diesel systems without economics, the load-following DG energy dispatch strategy shows superiority over the night dispatch strategy, for the load profile considered through the former goes with greater control-system sophistication.

It can be used to upgrade existing mono systems such as PV systems that have been rolled out in some peri-urban and rural areas in South Africa. Hybrid systems can also be sized to supply whole villages, schools, clinics in remotely located rural areas where there is no access to grid electricity as well as feed into the national grid. Use of bio-diesel can also help in decarbonising the environment and hence improve the livelihoods of the people.

Hybrid power systems can be sized to supply whole villages, schools and clinics in remotely located rural areas where there is no access to grid electricity while at the same time also feeding into the national grid.

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