An Effective Dispatch Strategy for Hybrid Power Management

Prema V., Swagatha Datta, Uma Rao K
Electrical and Electronics Engineering
RVCE
Bangalore
Email: premav@rvce.edu.in

***Abstract*—Decentralised power generation systems based on renewable energy can play an important role in hastening electrification of isolated areas in developing countries. Next generation, smart microgrids present sophisticated solutions for monitoring and visualising of all available resources and calculating of optimised schedules for dispatch of resources to ensure the most cost effective and sustainable operational strategy. This paper discusses an algorithm for economic dispatch of an off-grid microgrid comprising of a PV-array and wind turbine combined with a battery and variable speed diesel generator backup. The nature of the dispatch strategy developed has been compared to existing dispatch strategies. The sharing of the load amongst the various sources has been simulated for the given setup and the results are analysed.**

***Index Terms*—Off-grid hybrid, PV-photovoltaic, DG-diesel generator, VSDG-variable speed diesel generator**

I. Introduction

Electrical energy demands have increased sharply over the last few decades. A majority of the developing countries rely on fossil fuels for a bulk of their electric power generation. Increasing concerns about global warming and climate change call for a mandatory shift from fossil fuels to renewables. Owing to the lack of reliability associated with renewable generators, they need to be backed up by conventional diesel generators thus constituting a hybrid system. These hybrid systems incorporating renewables may be used as an alternative to diesel generator based systems in remote areas with low demographic density, where people have no immediate access to reliable electricity grids. Not only will off grid hybrid systems provide reliable power supply to such isolated areas but also reduce the overall carbon footprint of such facilities.

One of the most important aspects with regards to hybrid systems is deciding on a strategy which shall supply power to customers economically. The economic behavior or operation of the hybrid systems depend greatly on solving the problem of how power supplies are shared amongst generators. This has been the subject of study of several papers [1]- [2]. Various mathematical programs and optimization techniques have tried to address the issue of economic dispatch. Obtaining a good control strategy is extremely essential, since the performance of a hybrid energy system can be significantly affected by relatively small changes made in the control strategy.

J. F. Manwell [3] looks into the usage of VSDG for hybrid systems and the problems it poses. Amongst the many economic dispatch strategies that have been developed over the years for hybrid systems, very few have tried to address the problem of economic dispatch for a VSDG based systems. A possible dispatch strategy for a hybrid system with a variable speed diesel generator has been explored in this paper and the results presented.

II. Set up details

The hybrid system taken into consideration comprises of a 4KW solar installation, a 2KW wind installation, 2400Ah capacity battery, and a variable speed diesel generator with maximum power output of 10-KW, (10KVA). Figure 1 depicts the setup described. The PV module and wind turbine are the renewable generators connected to the system. The renewable generators are allowed to supply to the AC bus after inversion or to a charger which charges the battery bank. A dump load, in this case a desalination facility connected to the system receives a portion of the renewable power generated. The battery bank too supplies the AC bus after inversion. The diesel generator is directly connected to the AC bus which in turn supplies the AC load connected to the system.

III. Dynamic Dispatch Strategy

The hybrid system control strategy is divided into two distinct categories [7]:

- Dynamic strategy: This control strategy is based on magnitude and frequency measurements of output voltage

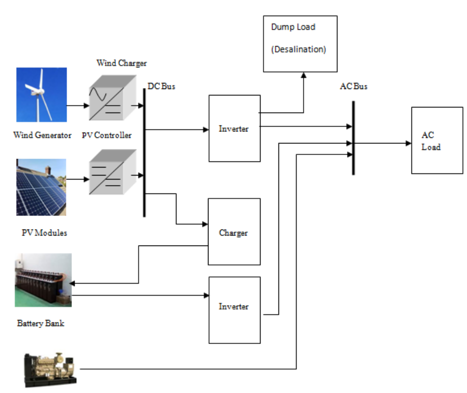

Fig. 1. Hybrid Power System

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for maintaining system stability at any point during the system operation. The time step of dynamic strategy is usually less than a second.
- Dispatch strategy: This strategy maintains the system power balance based on the power flow measurements. The time step of this strategy ranges from minutes to hours.

A dispatch strategy comprises of a control algorithm which facilitates the interaction amongst various components of the hybrid system, the power flows from various sources towards the user loads and dump loads and the charging and discharging of the energy storage systems.

IV. EXISTING DISPATCH STRATEGIES

There are various existing power management strategies for different types of hybrid power system. Several strategies reviewed by Barley in [1]- [4] are summarized below:

- Peak shaving strategy: In this strategy the battery is not intended for supplying average load demand within a time step. Battery power is used only as a buffer to meet short-term fluctuations of the load demand. Any excess renewable power is used to charge the battery. The diesel generator will only charge the battery under certain exceptional conditions when it has to be operated above the minimum loading condition which results in production of excess power.
- Load following strategy: In this strategy the renewable energy generator provides power along with the diesel generator to meet load demands. If there is any excess power produced from the diesel generator due to minimum loading conditions, and also the battery is not in its fully charged state, this power will be used to replenish the battery.
- Frugal discharge strategy: Battery power in this case is made available to the net load (load in excess of renewable energy production) in a time step. Diesel generator power is used to meet the load demand when running the diesel generator is more cost-effective compared to discharging the battery or when battery has reached its minimum SOC. Otherwise, the load demand is supplied by the battery.
- SOC set-point strategy: In the situation where the diesel generator is started and always operated at full power for maximum efficiency, the excess diesel power is used to charge the battery up to a defined SOC.
- Full power / minimum run time strategy: A diesel generator is operated at full power for a defined period of time. Battery capacity is mainly used for storing any surplus renewable energy. This strategy aims to increase the fuel efficiency of the diesel generator and prevent frequent start cycles.

Intelligent-based power management also has a major position in the area of hybrid power system research. Fuzzy logic [5], genetic algorithm [6], linear programming [2] and other optimization techniques are being resorted to, to solve the dispatch problem.

V. PROPOSED DISPATCH STRATEGY

A. Algorithm for proposed strategy

Figure 2 represents the flowchart for the proposed dispatch strategy for the system. The entire day is divided into 24, 60 minute intervals. For every such interval the algorithm is applied and dispatch strategy for that period decided upon. The algorithm is based on the following constraints:

1) Output of (Wind+Solar+Battery+DG)$\geq$ Load
2) The priority for selection of sources is in the order
   a) Renewable Generators(Wind+Solar)
   b) Battery
   c) DG

The order takes into consideration that maximum usage is made of renewable sources and minimal usage is made of battery and DG, thereby, minimizing cost and environmental impact. Wind and solar are given highest priority as they are non-polluting and inexpensive. Whenever the output of renewable generators is more than the load requirements, the additional power is used to charge the battery pack. The net load is defined as:-

Net Load=Total load-(Renewable generator output)

If both the renewable sources together are unable to meet load requirements, the battery comes into picture. The battery is never permitted to discharge above a certain rate to ensure its long-term efficiency and prevent deterioration. Also, care is taken never to discharge it beyond the 30% SOC mark. If SOC falls below this, the battery is unavailable. The battery pack aims to capture excess renewable energy and prevent wastage. Its discharge is given preference over DG usage so that it is again available for storing any surplus renewable energy while maintaining an overall small battery size. Also, unit cost of battery bank is lower than the unit cost of diesel generator. The last on the priority list is DG as its usage involves fuel costs, maintenance costs as well as large amount of polluting exhausts. If the above three sources are insufficient in meeting load requirements, the DG is resorted to, to meet the deficit load, defined as:

Deficit Load (Def) =Total Load-(Renewable generators output)-(maximum power output of battery)

A variable speed diesel generator (VSDG) has been used in this hybrid system. As compared to a constant speed diesel generator (CSDG), a VSDG has a much lower minimum loading and offers a wider operating range. An optimal strategy has been arrived at for the DG set with four different modes of operation, depending on the deficit load (Def) it has to supply:

1) Def is less than 25% of Max Rated Output of DG. This is called the Very Low Operating Mode
2) Def is between 25% to 50% of Max Rated Output. This is called Low Operating mode
3) Def is between 50% to 75% of Max Rated Output. This is called Medium operating mode
4) Def is between 75% to 100% of Max Rated Output. This is called High operating mode.

The amount of load actually supplied by the DG is decided depending on the operating mode. If the deficit to be met is

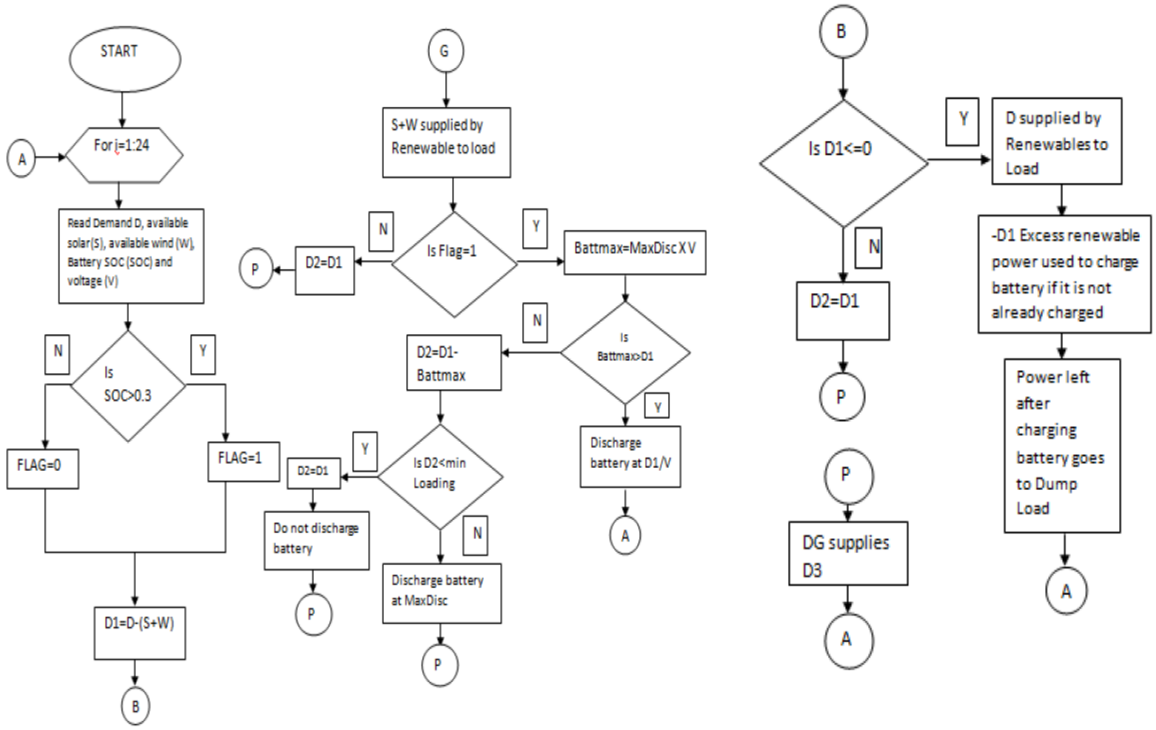

Fig. 2. Flowchart for Proposed Algorithm

lower than the minimum loading of the VSDG, then discharge of the battery is avoided and the whole net load is drawn from the DG and thus operation of DG above its minimum loading is ensured.

B. Comparison with Existing Strategies

All the standard algorithms discussed in section IV were for systems with CSDG (Constant speed diesel generators). For the given set up comprising of PV, wind, battery and VSDG, a strategy which may be considered to be a mix of frugal dispatch strategy and peak shaving strategy has been developed and simulated. The frugal dispatch strategy allows for battery discharge in the standard time step only if its usage is cheaper than DG operation. The DG is found to be cheaper near its full load operation. Thus when the battery is incapable of solely meeting the net load, it is always preferred to draw the full net load from the DG as compared to from a mix of both battery and DG usage. The peak shaving strategy meanwhile allows for combined usage in case of load peaks and extreme deviations from the standard load profile and avoids using the battery in the standard time step.

A variable speed diesel generator (VSDG) has a wider operating range and is capable of operating at optimum speeds for different output power, resulting in higher efficiency of the generator operation. In a variable speed generator, the engine is operated at relatively low speed for low power demand and vice versa. In contrast to the adverse light load operation of the CSDG, the life span of the variable speed engine may be increased due to the engine being operated at low speed for low loads.

Thus it was considered to be feasible to go for the preferential dispatch order with battery always being checked for availability before DG and always opting for a battery above its minimum SOC to discharge. Even in cases where the battery alone would be unable to meet the net load in its full discharge rate, a combined strategy is opted for, in which the battery discharges at its maximum rate and only the deficit still left is supplied by the DG. Care is taken to ensure that the minimum loading constraint of the DG is always met. Since its a VSDG, the performance of the system is good for light loads and there is no need for forcing the DG to operate above 40% of the power rating at rated speed. The operating range of the variable speed engine allows the system to extract more power for efficient system operations for even light loads. Thus the VSDG brings in greater flexibility to the dispatch strategy without any loss of efficiency.

VI. Simulation and Results

A. Database

The data required for running the simulation algorithm was collected, organised, and stored in a database. The information stored in the database include:

- Available renewable energy generators viz. Solar and wind, power production capacity
- Power output of renewable generators, for every hour
- Load profile for every hour
- Diesel generator capacity
- Battery bank capacity
- Minimum and maximum SOC of battery bank

B. Load sharing for a day

The simulations as per the algorithm were carried out for a 24 hour period for a day starting from 0.00 am. The peak load for the given load data for a day was 8.36kW and the average load was 1.879kW. The battery was assumed to have an initial SOC of 0.6.

Figure 3 represents the variation of load, solar and wind for a particular summer day (July 12th). Also it depicts the sharing of the load amongst renewable generators, battery and DG and the variation of SOC. Solar in its peak hours supplies the load and uses any surplus power to charge the battery. The battery has been assumed to be in its 60% SOC initially and was found to be at 65% at the end of the simulation period. The overall battery operation is decently balanced and the battery is available in nearly the same state in the beginning of a fresh day. The DG usage is found to be limited to the peak load hours. The startups have been limited to only two. The wind as available is directly used to contribute to the load and excess diverted to the battery for charging. The overall percentage of load shared by each of the sources for the entire day has been compiled in the table I

TABLE I
RESOURCE DISTRIBUTION ON 12 JULY 2013

Source	% Load shared by the source
Renewable Sources	44.83
Battery	30.96
DG	24.20

C. Case Study for different resource availabilities

For the same load profile, the algorithm was executed for different days of the year (representing different seasons as shown in Table II) during which the renewable source availability is different.

TABLE II
RESOURCE AVAILABILITY FOR DAYS OF FOUR DIFFERENT SEASONS

Date	Resource Availability
28th December	Low solar, Low wind
10th March	High solar, Low wind
2nd August	Low solar, High wind
12th July	High solar, High wind

The resource distribution for all the four cases has been tabulated in Table III.

Date	% Contribution to Load		
	Renewable	Battery	DG
28th December	31.25	29.42	39.33
10th March	33.00	34.52	32.48
2nd August	37.77	27.75	34.48
12th July	44.83	30.96	24.20

TABLE III
RESOURCE DISTRIBUTION FOR DIFFERENT DAYS

VII. CONCLUSION

An algorithm was successfully developed in this paper for a PV-Wind-Battery-VSDG system and simulated. The advantages of using a VSDG over a standard CSDG have been explored. Further study needs to be done on the possibilities represented by VSDG based hybrid systems. With the DG contributing to less than 34% (on an average) of the daily load, such systems can be a less polluting alternative for purely DG based off-grid systems. Transitioning to such systems in developing countries will make way for rural electrification with lower environmental footprints.

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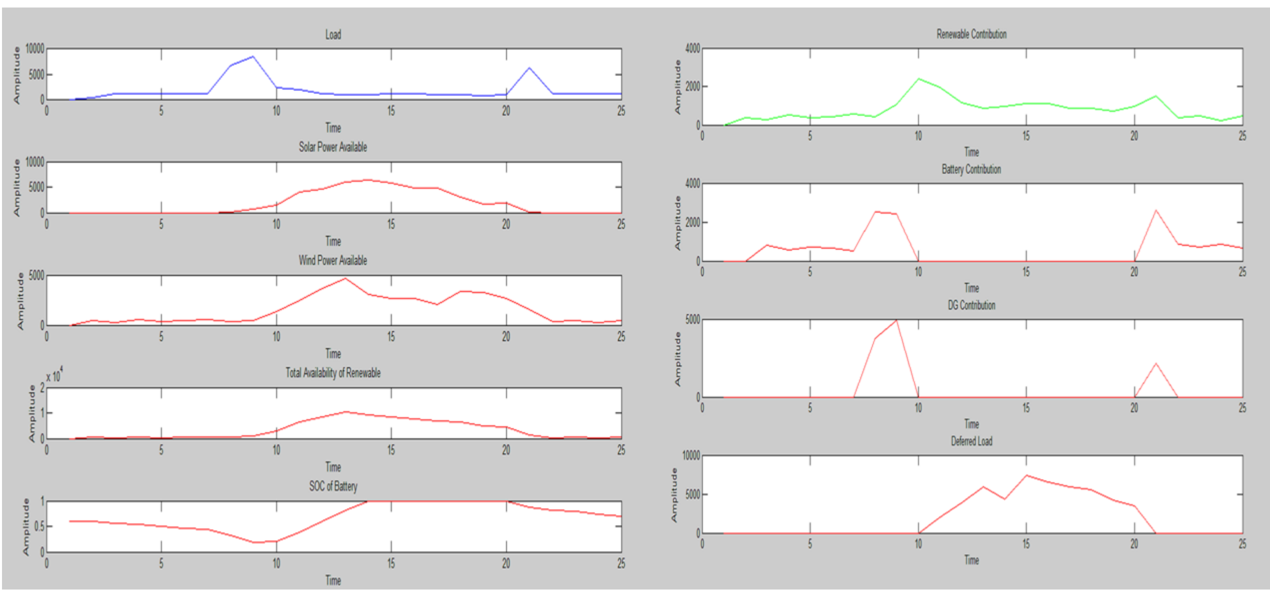

Fig. 3. Availability of renewables and contribution of individual sources to load for July 12th