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Integrated Intelligent Power Management Strategy (IIPMS) to optimize green energy usage in standalone microgrid

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***Abstract*—The increasing demand for renewable and clean energy has mandated the research for maximizing the energy extraction from the available sources. It is also essential to devise the generation systems in such a way as to optimize the usage of all the available resources in the area with minimum dependency on non-renewable sources. The system design should also consider the costs involved for installation, generation and maintenance and make it affordable to the common masses to ensure effective utilization. This paper proposes a power management algorithm of a microgrid comprising of PV, wind, DG and a battery. The complementary nature of wind and solar power gives the advantage that the availability of renewable energy is there throughout the day, thus reduces the usage of DG. The microgrid is optimally sized using PSO algorithm. The power management algorithm runs in two stages, source side management and Demand side management. The inputs to the source side management algorithm are original load schedule and renewable forecast for the day. The output of the algorithm shows the contribution of each source over the day. The DSM algorithm analyzes the usage of various sources and shifts parts of loads to reduce the DG usage. The strategy is intelligent as it checks the availability of renewable energy and dynamically shifts the load so that DG usage will be minimized.**

***Index Terms*—hybrid microgrid, Demand side management, power management, load shifting**

I. Introduction

The energy demand of human population is booming and fossil fuels are depleting rapidly, coercing man to curtail his dependency on non- renewable energy sources. So it is the demand of the hour to switch to renewable sources for power generation. The last decade has seen tremendous improvements in the renewable energy based technology developments [1]. Distributed Generation systems serve a key role in providing electricity to isolated locations in a developing country like India [2]. The complementary behaviour of wind and solar energy can be considered as an advantage in setting up a hybrid microgrid with these sources for distributed generation [3]. Diesel generators and battery system could back up these sources to make the system reliable. The primary aim of any power management strategy is to maximize the use of renewable sources and to reduce DG usage [4].

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There are many works available in literature related to power management of hybrid microgrids. In [5], HOMER software is used to design and optimize the performance of a hybrid power system. In [6], different power system models were explored and the sensitivity analysis was conducted. In [7] a roof-top microgrid is designed to work optimally. The actual building data is considered for the analysis. A comparative study of the performance of a grid-connected system with a PV-wind-battery microgrid. The net cost and CO2 emission are found to be reduced.

In [8] a DSM strategy is applied to a real and patented HPS with PV, DG and batteries. The loads are classified as permanent, shiftable, divisible, etc. The control management decides how to make use of the sources effectively. In [9] a vulnerable microgrid with minimum resources is considered to highlight the effectiveness of DSM. The DSM controller was built using MATLAB Simulink. The results are shown for different temperature conditions and different load conditions. In [10] a new optimisation technique called mixed integer technique is proposed which is based on forecasting models. A neural network model is also proposed for 2-days ahead forecast. The predicted solar and wind power are fed to the controller. The results show operational costs of microgrid are reduced for certain load profiles. [11] is an interesting work based on a hybrid microgrid in an island in Antarctica where around 100 people spend summer each year and population drops to 15 in winter. Use of renewable energy is an eco-friendly replacement for DG in such places. A novel DSM strategy is proposed where the laundry is shifted to the time period where wind is available.

As seen from the literature, stand-alone hybrid systems can choose from the dispatch strategies, viz. frugal dispatch strategy, cycle charging strategy or load following strategy to achieve best use of the renewable sources with efficient and minimal usage of backups sources. Diesel generators are customarily used to augment the reliability. The critical issue with such a setup is that the time of renewable energy availability and peak load demand do not match resulting in over-use of DG during peak load hours. The best solution for this is to employ a DSM strategy. This may comprise shifting

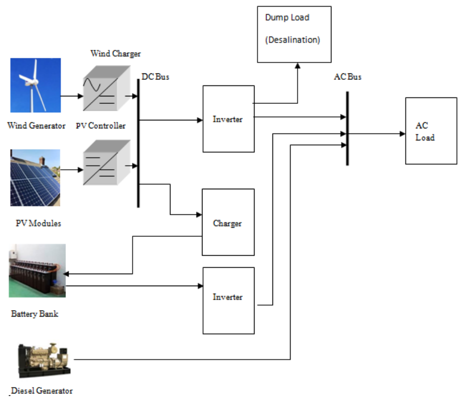

Fig. 1: Hybrid Power System

some of the loads from the peak load hours to periods where renewable availability is maximum resulting in a reduced in DG usage.

Various methodologies have been proposed and discussed to work towards this noble cause. The First step in designing a hybrid micro grid is to optimally size the system. Sizing of a micro grid is challenging due to the random behavior of renewable energy sources. In this work, Particle Swam Optimization (PSO) is used to develop algorithms to find the optimal size of micro grid. The next step is to formulate a power management strategy ensuring economic feasibility. The dispatch strategies decides the operation and performance of microgrids.This paper tries to analyze the potential that load shifting based DSM algorithms may have in increasing the utilization of renewables in an off grid hybrid system. An Integrated Intelligent Power Management Strategy (IIPMS) has been developed which integrates supply side and demand side management to manage the power shares among various resources optimally. The algorithm dynamically shifts the non-critical loads to time slots where renewable energy is available, thus minimizing the DG usage. The algorithm has been tested for various weather conditions. The paper is organized as follows: Section II and III give details of sizing of microgrid. Section IV to VI discuss source side management and demand side management respectively. Section VII gives results and discussions. Section VIII concludes the paper.

II. Modeling of System Components

The considered test system consists of solar panel, wind turbine, diesel generator and battery. As shown in Fig. 1, the system configuration is such that the ac load can be fed directly by renewable sources. In the absence of both solar and wind, the load is fed either by the battery of diesel generator.

A. Output of Solar PV

The power output per unit area of PV array is given by the equation 1

$$P_{PV} = \mu_{PV} \times I \times S \times (1 - 0.005(t_{air} + 25)) Watts \qquad (1)$$

Where, μ_{PV} is the conversion efficiency of PV array (assumed to be 35%);

I is the Solar Irradiance;

S is the area of PV array;

t_{air} is Air Temperature.

The power generated from the solar PV system is calculated from the solar irradiance values collected from real time data collected from a weather station in Bagalkot, India. The authors have developed predictive models to get day-ahead solar irradiance [12].

B. Output of Wind Turbine

The wind power output is determined using the formula given in equation 2

$$P = \frac{1}{2} C_p A \rho_{air} v^3 Watts \qquad (2)$$

Where ρ_{air} is the air density (assumed to be $100 kg/m^3$);

A is the area swept by the rotor of wind turbine; The area swept by a 1kW wind turbine is $10m^2$

v is the wind speed (m/s).

The power generated from the wind turbine is calculated from the wind speed values collected from real time data collected from a weather station in Bagalkot, India. The authors have developed predictive models to get day-ahead wind speed [13], [14].

C. Diesel Generator

The incorporation of diesel generator as one of the power source in the hybrid micro grid minimizes the size of energy storage device. Diesel generator serves as a back up source when battery and renewable sources are unable to meet the peak demand. The main factor to be considered in the design of diesel generator is the loading conditions. Unloaded or lightly loaded conditions need to be avoided. Thus the hourly consumption of fuel and efficiency of the diesel generator are major parameters to be considered in the design. The hourly fuel consumption can be expressed by the formula shown in equation 3,

$$f(t) = a_1 P(t) + a_2 P_r \qquad (3)$$

where f(t) is the fuel consumption, P(t) is the power generated and P_r is the rated power. a_1 and a_2 are constants and empirically approximated as 0.246 and 0.08415 respectively.

D. Battery Bank

The battery banks need to be designed and selected in such a way that, it should have sufficient capacity to store the excess energy in the micro grid. When the renewable supply is not available, the micro grid should be able to use the energy stored in the battery. The life of a battery depends on the number of charging-discharging cycles, State of Charge (SOC) and Depth of Discharge (DOC). Lead Acid battery of capacity 800Ah is chosen for this work.

III. Sizing of the micro grid using Particle Swarm Optimization (PSO)

The financial feasibility of a micro grid rely upon the optimization of generation and storage units. The proposed optimization strategy in this chapter takes care of both technical and economic considerations in which system cost, reliability and availability of renewable sources are considered.

A. Cost Analysis

The cost of the system comprises of the price of PV panels, wind turbines, battery banks, and power electronic converters. The O&M cost and replacement cost also need to be considered. If the interest rates of the system components are taken into consideration, the Capital Recovery Factor (CRF) also need to be incorporated in the cost function. Thus the net cost of electricity (CoE) can be calculated using the formula shown in 4

$$CoE(Rs/kWh) = \frac{NPC(Rs) \times CRF}{\sum_{h=1}^{24} P_{load} \times h(kWh)} \quad (4)$$

Where

$$CRF = \frac{i(i+1)^n}{(i+1)^n - 1} \quad (5)$$

NPC- Net Present Cost
i-interest rate
n- system life period
n is usually taken as the life of PV panel

B. Reliability Analysis:

The reliability of the system is estimated by calculating a statistical parameter called Loss of Power Supply Probability (LPSP). There can be two reasons for failure of power supply. One is due to the non-availability of renewable energies and the other reason can be any technical failure. LPSP can be calculated with the equation 6

$$LPSP = \frac{P_{Load} - P_{PV} - P_{Wind} + P_{SOCmin} + P_{Diesel}}{\sum P_{Load}} \quad (6)$$

The worst case condition, $P(t)_{load} > P(t)_{gen}$ is considered in this analysis for the calculation of reliability.

C. PSO Algorithm

Particle Swarm Optimization is one of the evolutionary algorithms based on swarm intelligence and their position and movement in a defined search space. A particle represents an insect in its group. The movement of each insect in a swarm or block depends on two factors: one on its own intelligence and the other on the intelligence collective to the group of insects. The general behavior of a swarm is that if any particle find the easiest path to food, then all other particles immediately start following it. PSO is inspired by this behavior of a swarm of insects.

In any optimization problem, the swarm is the entire search space limited by the pre-defined upper and lower boundary. Each particle in the entire search space is a collection of variables defined for the problem under consideration. The optimal solution is the set of values of variables in a particle for which the objective function is minimized. Position and velocity are two distinct characteristics of each particle, generally being initialized with random values. This is taken as initial solution. Thus each probable solution in PSO population is a particle. In each iteration, each particle move towards the optimal solution. Each particle obtain local best and global best solution from all particles.

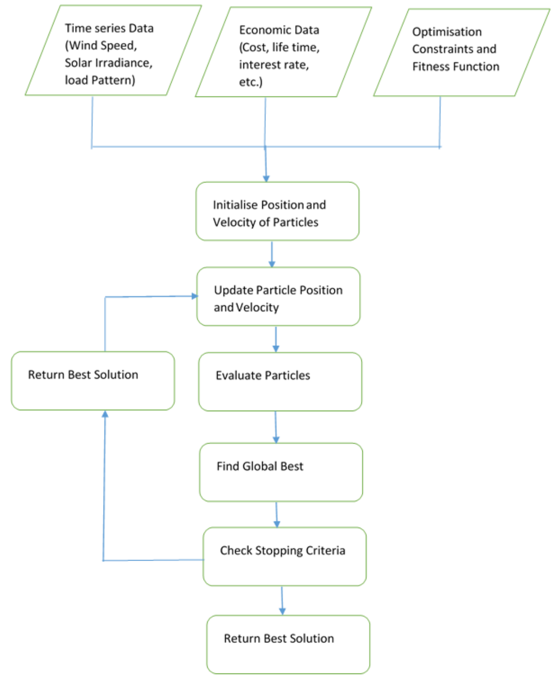

Fig. 2: Flow chart for PSO Algorithm

In the problem of micro grid sizing using PSO, the objective function is to minimize Cost of Electricity (CoE) and LPSP. A particle is the set of the following parameters. nominal power of PV, number of days of autonomy, number of houses and number of wind turbines. The flow chart of the algorithm for optimal sizing of micro grid is shown in figure 2. The constraints for the optimization problem considered in this study are listed below:

1) Number of houses connected to micro grid is equal to 10
2) Renewable energy factor (RF) is always greater than zero. The renewable factor is given by the equation 7. This parameter indicates the percentage of power dispatched from renewable source to the diesel power. If there is no usage of diesel generator, RF is 1.

$$RF = 1 - \frac{\sum P_{Diesel}}{\sum P_{PV} + \sum P_{Wind}} \quad (7)$$

3) The lower bound of these parameters are initialized as shown in table I.

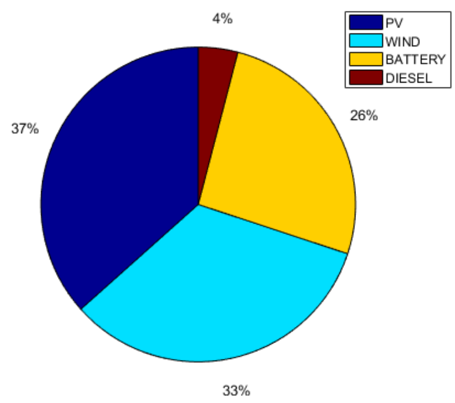

Fig. 3: Percentage of power delivered by various sources

TABLE I: Bounds of search space

Parameter	Lowest Bound	Upper Bound
Nominal Power of PV Panel (kW)	1	5
Number of Days of Autonomy	1	4
Number of houses in the micro grid	1	10
Number of wind turbines	1	10

The population is initialized by random selection of position and velocity of the particles. The best solution returned by the algorithm will have the least CoE and LPSP.

D. Optimization Results

The optimization algorithm is run with the load data of 10 houses in a village. The time series data for solar irradiance and wind speed were the same which was fed to HOMER sizing algorithm. The number of iterations was chosen as 150. A comparison of the results of sizing using optimization algorithm and HOMER is tabulated in table II. It can be observed from the table that the CoE is Rs. 26.35. The sizing matrix provided by HOMER software showed a CoE of Rs. 27.39.

TABLE II: Comparison of Sizing Results with HOMER and PSO algorithm

Components of Micro grid	Size in HOMER	Size in PSO
Power of PV Panel	4kW	4kW
Power of Wind Turbine	2kW	1kW
Power of Diesel Generator	10kW	10kW
Days of Autonomy	–	1
LPSP	–	7%
CoE (Rs/kWh)	27.39	26.35

The percentage of power delivered by solar panels, wind turbine, battery and diesel generator for a day is shown in figure 3. It can be seen that the DG usage is minimized to 4%.

IV. Load Shifting

Load Shifting is one of the popular DSM strategies employed in the many industry applications. In load shifting, peak load is reduced by shifting some of the loads to off-peak hours. This improves the load factor by flattening the load curve and cuts down the cost of energy.

Since the DG usage pattern is different in different economic dispatch strategies, obtaining a generalized shifting algorithm based on the principles described may result in inaccurate results. A better solution may be obtained by directly connecting the DG usage in critical areas obtained as per the dispatch strategy to the load shifting strategy. This would ensure all necessary factors are taken into account as the DG usage for the initial load curve as per the chosen dispatch strategy represents a definite mismatch as well as takes into the account the specific properties of that particular strategy .

The loads need to be categorized in shiftable and non-shiftable loads to employ load shifting. Non-shiftable loads include essential loads such as lights, fans, refrigerator, etc. Other loads such as washing machine, geysers, etc. can be scheduled to the time durations where renewable sources are available so as to utilize renewable sources to the maximum. This also helps in minimizing the DG usage.

V. Supply side Power Management/ Dispatch Strategy Algorithm

The power management algorithm is developed on a day-ahead basis. Users are aware well in advance of their daily consumption needs. Thus an approximate schedule for the operation of various loads is prepared and uploaded. The daily load plan must also characterize the loads as shiftable and non-shiftable. The day-ahead renewable availability can be estimated by an effective forecast model. Thus both the day ahead renewable availability and load demand forecasts are fed to the algorithm. The algorithm is based on the following constraints:

1) The total power output from all the sources is greater than the load demand
2) The minimum State of Charge (SOC) of battery is 30% The renewable sources will have the the highest priority, followed by battery and diesel generator.

The priority is set to ensure that renewable is energy is utilized to it maximum capacity so that the usage of battery and diesel is minimized. This reduces the overall cost and CO2 emission. In the absence of renewable energy, load is supplied by battery. The discharge limit of the battery is set to 30%. The battery usage has higher preference than diesel as the unit price of battery is lower than that if diesel generator. DG is the large resort as its usage involves fuel costs, maintenance costs in addition to letting out a large amount of polluting exhausts. The source side management (dispatch strategy) algorithm is run for the original expected load schedule and renewable forecast for the day. The output of the algorithm shows the contribution of each source over the day.

VI. Demand Side Power Management

The proposed DSM algorithm employs load shifting strategy. The power management algorithm gives the time slots where DG usage is maximum. This occurs when both renewable sources and battery are inadequate to meet the load. The shiftable loads during these time slots need to be shifted to areas with higher renewable availability. The DSM algorithm works in 5 stages:

1) Identification of time slots with DG usage from which the load can to be shifted to other time slots.
2) Reducing the load in such time slots to a magnitude closest to the renewable availability.
3) Grouping the elements to be shifted
4) Identification of time slots where there is excess renewable available
5) Shifting the identified loads to these time slots

This algorithm aims to eliminate the majority of shiftable loads in these time slots with the objective of reducing the load to match the availability of renewable energy. All the identified re-locatable loads need to be allocated to other time slots. The time slots with the highest excess of renewable energy were identified and shortlisted by a comparison of the availability during different intervals. The re-locatable loads identified earlier were positioned to these slots. The power management algorithm was re-run for this newly shifted load curve. This strategy contributed a sizable reduction in DG usage. Thus if the load is planned and shifted as per the output of the DSM algorithm, it may result in a day with much lower DG usage.

VII. Results and Discussions

A. Load Sharing of a day

Figure 4 and figure 5 show the load, renewable and DG curved before and after DSM respectively. It can be seen that after load shifting, there is a load pattern almost follows the renewable availability pattern. This has resulted in zero DG usage.

B. Case Study for different weather conditions

The algorithm was executed for different days of summer, winter and spring seasons. Table III shows the percentage of the resource distribution for these days with and without DSM strategy. It can be observed from the table that in all the cases there are significant improvements in the percentage of load shared by renewable energy when DSM is incorporated. India being a tropical country shows large variations in weather conditions, summer hovers around 40°C and winter around 10°C. Thus the usage of air conditioners and coolers are high during summer and usage of room heaters and geysers are high during winter. It can be observed from Table IIIthat during summer and winter, where the load usage is heavy, the DG usage is reduced by 50% with load shifting. During spring season, where availability of renewable energy is good and load usage is moderate, the percentage shared by DG is dropped by almost 90%.

VIII. Conclusion

The proposed IIPMS employs load shifting strategy to effectively use green energy. An optimally sized hybrid microgrid consisting of PV, wind, DG and Battery was designed using HOMER software. The inputs given to the power management strategy were one day-ahead predicted values of solar and wind power, day-ahead load schedule and the State of Charge of battery. The algorithm shifts the load accordingly to make the DG usage minimal. The algorithm has been tested for various weather conditions and it was found that percentage of load shared by renewable energy sources have considerably increased in all the weather conditions. Such a DSM strategy may assist in day ahead planning and scheduling of loads to improve the utilisation of renewable sources connected to the hybrid system for any chosen dispatch strategy. Increasing the contribution of renewables and reducing the DG usage directly translates into lower costs and reduced emissions.

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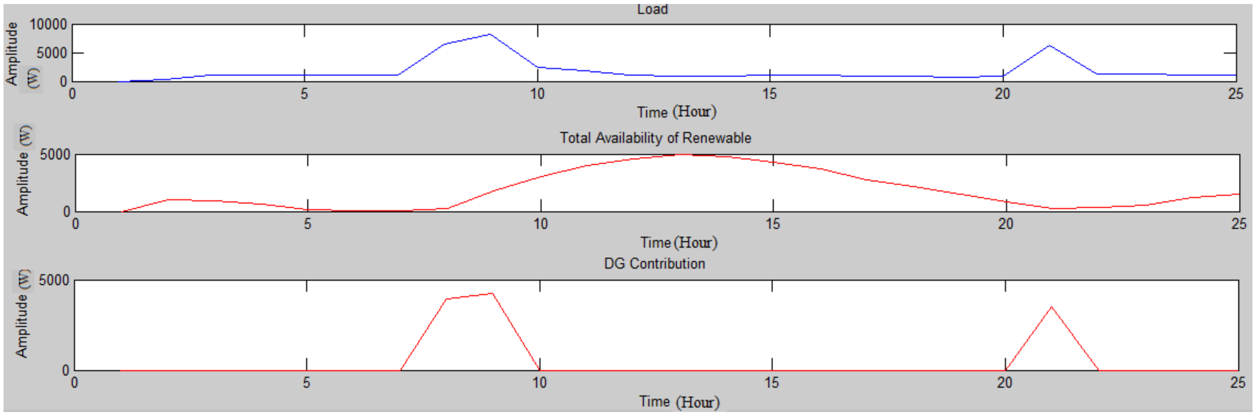

Fig. 4: Renewable availability, load curves and DG usage(before DSM) as per the economic dispatch algorithm

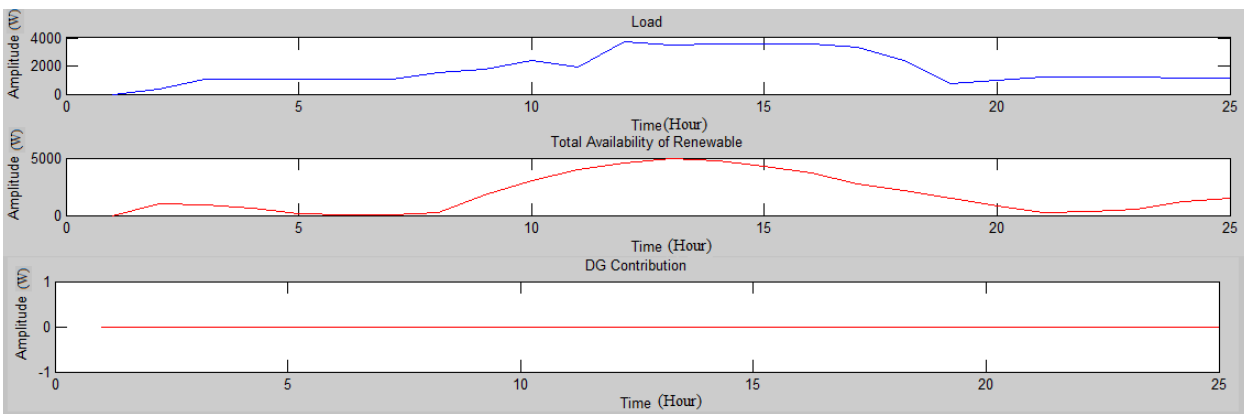

Fig. 5: Renewable availability, load curves and DG usage(after DSM) as per the economic dispatch algorithm

TABLE III: Resource Distribution for different weather conditions

Weather	% of Load without DSM			% of Load with DSM		
	Renewable	Battery	DG	Renewable	Battery	DG
Summer (10^{th} March)	40.65	31.02	28.33	69.82	17.29	12.89
Spring (2^{nd} Aug)	49.83	20.46	29.71	78.59	20.49	0.92
Winter (28^{th} December)	49.13	25.46	25.41	70.48	13.95	15.57