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Multi Master Inverter Scheduling for Solar Photovoltaic Systems

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***Abstract*—As the world now is shifting towards the renewable energy sources for power generation, the distributed energy generation unit's standards like reliability, lifetime and efficiency should be as good as the conventional energy generation system's standard. Out of the many renewable energy sources available, solar energy harvesting technology is the major source of the renewable energy in the world. In the solar photovoltaic power generation systems, DC power generated by the solar PV panels needs a solar inverter for connecting it to an ac utility grid. But, the efficiency and lifetime of the solar power inverter is low due to the losses and damage caused by the higher operating hours of the solar inverters. This project aims to improve the efficiency and to prolong the lifetime of a solar inverter, by proposing the multi master inverter scheduling concept. The main objective of this project is to develop an optimisation algorithm for reducing the operational hour of the inverter units and also to improve the efficiency of the inverter during power conversion by providing a proper load sharing algorithm for inverters. The inverter's efficiency varies according to the load and this variation helps in determining the number of inverter units to be connected to the system for obtaining the maximum efficient power converting condition.**

***Index Terms*— Maximum Power Point Tracking Algorithm; Multi-master inverters; Multi-objective optimization algorithm.**

I. INTRODUCTION

The solar energy harvesting system is not only the most popular and emerging recent technology, but also it is the need of the hour in the near future because of the fast depletion of the fossil fuels which is used by the conventional power plants. So, the improvement in the efficiency and the reliability of the solar energy trapping power plant is much essential in this rushing trend. The solar photovoltaic systems consists of many components and inverters are one of the components that are more prone to failure and so the reliability of the solar inverter becomes low. It is the most unreliable component of a solar photovoltaic system and highest probability for failure occurrence.

II. BLOCK DIAGRAM

The overall block diagram of the proposed Solar PV system is shown in figure 1.
The power generated from the solar panel is fed to a DC to DC converter. As the power obtained from the solar panel is a DC power, a DC to DC converters is used. On using a DC to DC converters, the variable input voltage is converted into a steady, fixed and reliable output voltage. As t he electrical barrier is not present between the

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input and output of the converter, the converter is of non-isolating type. The DC to DC converters can step up or step down voltage levels (analogous to an AC transformer).

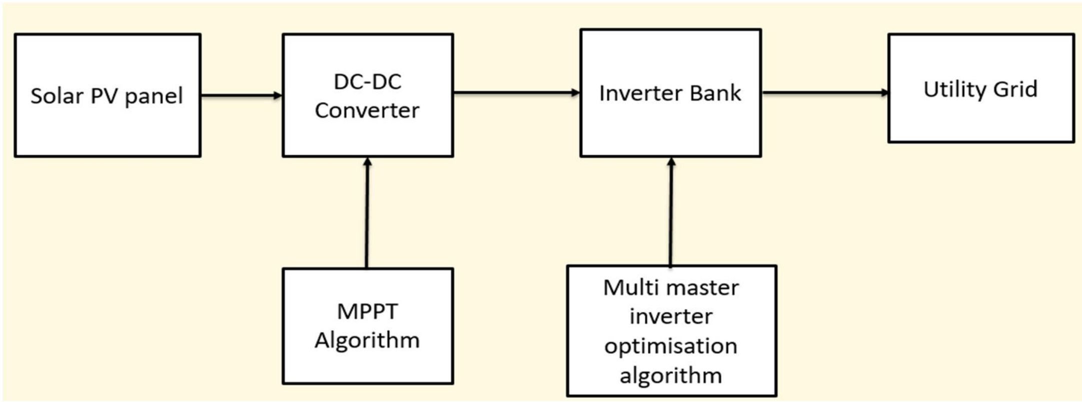

Figure 1. Overall block diagram of the proposed photovoltaic system

The insolation of the sun varies from time to time and when a load is directly connected to the solar panel, the operating point of the panel will rarely be at peak power. The output electrical power obtained from the solar panel is not always equal to the maximum power.

The intention of Maximum Power Tracking Algorithm (MPPT) is to extract the maximum available power from PV module by making them operate at the most efficient voltage (maximum power point). This is done by sensing the panel output voltage and panel output current. The MPPT tracks the best voltage at which it is to be operated in order to obtain the maximum power. The IV curve and the PV curve is plotted and the voltage at which the maximum power is obtained is conveniently found by the MPPT algorithm. So, the voltage level, thus found, is used to adjust the duty cycle of the MOSFET in boost converter.

The Maximum Power Point Theorem algorithm is used in dynamic tracking of the optimal operating condition of the solar panel to obtain the maximum power output from the PV panel. This power output is then fed to the inverters for DC to AC conversions and then the output AC power can be supplied to the utility grid.

The solar power inverters inverts the DC to AC power by the usage of the semiconductor switches like transistors. The efficiency of the solar inverter must be as high as possible in order to improve the overall efficiency of the solar photovoltaic system.

Reliable solar power systems require the best quality inverter with a robust cooling system. Low quality inverters have unfortunately failed in the harsh climate.

If an inverter operates all through the day, the chances of failure are more. So, an idea of using multiple low rating inverter instead of single bulky inverter is proposed. The proper scheduling of these multiple inverters based on an appropriate scheduling algorithm will ensure a better operation.

III. Multi Master Inverter

Five Siemens SINACON PV inverter are taken and the optimisation algorithm has been performed on it for obtaining good efficiency and reduced runtime. The overall block diagram for the proposed project is shown in the figure 2. The multi-objective optimization algorithm appropriately schedules the five solar photovoltaic inverters to increase the efficiency and lifetime.

Five inverters have been designed in the Simulink and the provisions to measure their corresponding run time, input power, output power, input energy and output energy have been made. These parameters are used during the calculation of the efficiency of inverter.

Each inverter used is of 1MW capacity and the graph showing the variations in efficiency for different loading condition is plotted and this plotted graph is shown in the figure 3.

This curve shows that the efficiency is at zenith (99%) during 30% loaded condition and the efficiency drops on either sides. The efficiency of the curve reduces with the higher slope value when the loading is reduced from 30% towards 0% loaded condition (i.e. left hand side of 30% loaded condition), whereas the efficiency curve gradually decreases if the loading is increased from 30% towards 100% loaded condition (i.e. right hand side of 30% loaded condition). This inverter is employed in this project due to better performance and this project aims to propose a multi-master inverter scheduling for these prevailing five Siemens PV Central inverters.

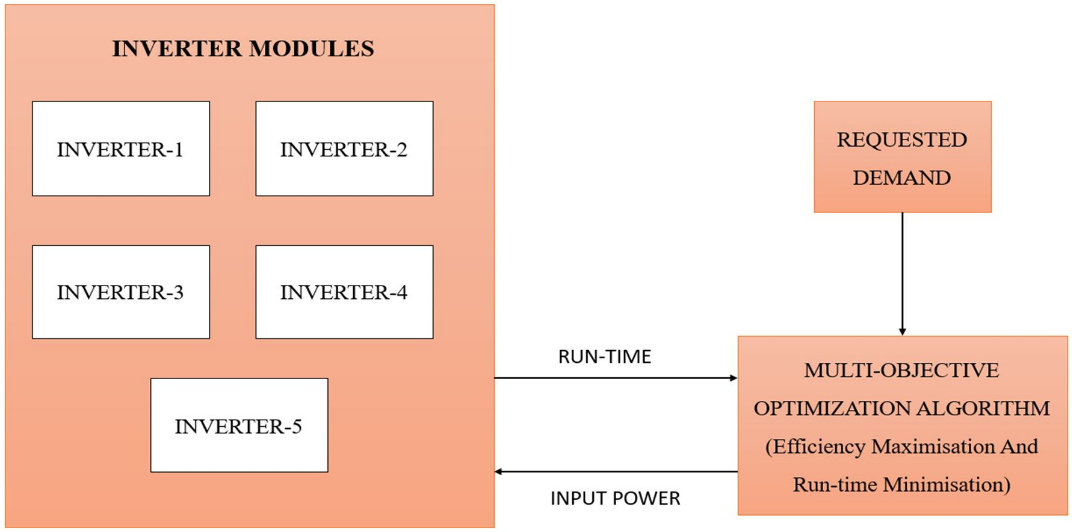

Figure 2. Block Diagram of the Proposed Model

The efficiency curve of the inverter is a non-linear curve. So, this optimisation problem is obviously a non-linear problem and the maximisation of the curve is done by the computational algorithm.

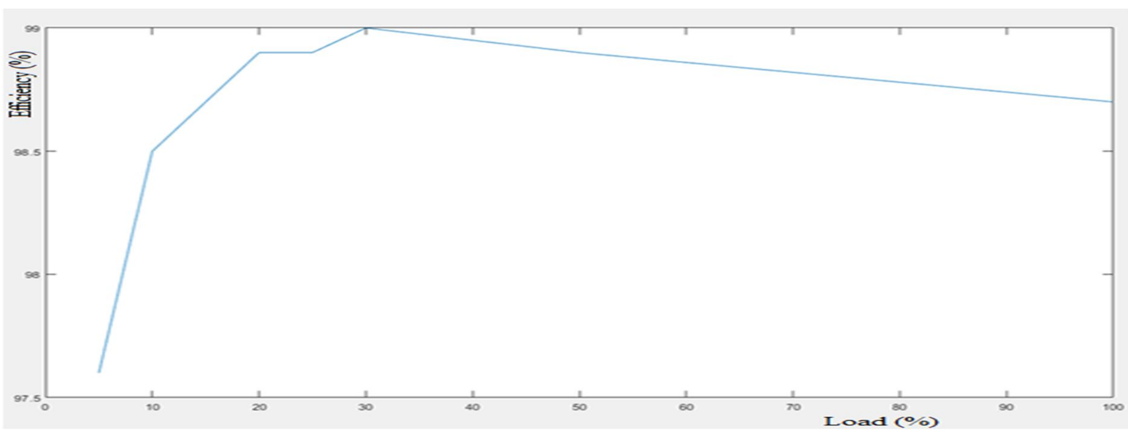

Figure 3. Load vs. Efficiency curve of SINACON PV inverter (Interpolated)

IV. Multi Objective Optimization Algorithm

The main intention of this optimisation algorithm is as follows.

- To reduce the working hours of the inverter.
- To operate the inverter at the maximum possible efficiency.

The run time minimisation targets to allocate equal loading for all the five inverters so as to make the overall energy delivered by each inverter same when calculated over a long period of time. This ensures that all inverters would retire at the same age and hence the replacement of all the five inverters can be done at the same time easily. Thus, the life time of all the inverters is identical.

The running time of all the inverters are measured dynamically and the loading is done accordingly i.e. high loading for inverters with low run time. As the load taken by each inverter is varying dynamically, both the amount of power delivered and the operating time has to be considered. Hence, the loading of the inverters should be done by minimising the energy supplied by each inverter. This is represented in the equation 1.

$$\text{Energy} = \text{Power} * \text{Time}$$

….. (1)

The algorithm used for prioritisation (ranking) of the inverters based on the minimal runtime is provided below.

1. The cumulative energy supplied by each inverter is taken from all the five inverters.
2. The total energy supplied by all the five inverters are obtained by adding all the five inverter's individual energy output.
3. These two values are divided and this average value is compared and the minimum value is found and accordingly, the inverters are ranked.
4. These rank values are fed to the combined optimisation algorithm.

The lookup table for the inverter's efficiency curve is obtained from the Siemens datasheet and is shown below in the table 1. The table shows the fact that the efficiency can be maximized by making the inverters to operate at around 30% load. So, an optimization algorithm is written for dynamically allocating the load to all the inverters with high efficacy.

TABLE I. SIEMENS PV INVERTER DATA

LOAD (IN %)	EFFICIENCY (IN %)
5	97.6
10	98.5
20	98.9
25	98.9
30	99
50	98.9
75	98.8
100	98.7

The algorithm used for loading of the inverters of capacity 1MW based on the maximum efficiency is provided below.

1. When the load requirement is equal to 1.5 MW, all the five inverters are allocated 0.3 MW individually to meet the load. In this case, the inverters are loaded 30% and hence, the efficiency is maximum.
2. When the load requirement is greater than 1.5 MW, the load is divided by five and then allocated to all the inverters.
3. When the load requirement is lesser than 1.5 MW, the load is divided by 0.3 MW to obtain the number of inverters to be scheduled and those number of inverters are allocated 30% load (i.e. 0.3 MW). If the divided value is decimal, then there exists some remaining load which is less than 0.3 MW. This remaining load is divided equally among the already allocated inverters.

The efficiency maximization optimization algorithm and the run-time minimization algorithm are combined and the code is written on Matlab R2018 simulation. The coding provides ranks to the inverters based on their respective running hours or the energy supplied. Based on these ranks, the priority of inverter to take up the next load is given.

The combined optimization algorithm implements both the efficiency maximization algorithm and the runtime minimization algorithm. When the load value is less than 0.3 MW, the inverters with the low run time is prioritized for taking up the load. This ensures that all the five inverters are able to supply an equal amount of energy over a long period of time and hence, the retirement of all the solar inverter modules is at the same time.

V. SIMULATION RESULTS

The combined optimization algorithm implements both the efficiency maximization algorithm and the runtime minimisation algorithm. When the load value is less than 0.3 MW, the inverters with the low run time is prioritised for taking up the load. This ensures that all the five inverters are able to supply an equal amount of energy over a long period of time. The simulation results are obtained for the input loads 0.1 MW, 0.4 MW, 0.5 MW, 3 Mw, 4.5Mw, 0.7MW and 0.2MW and is shown in figure 4.

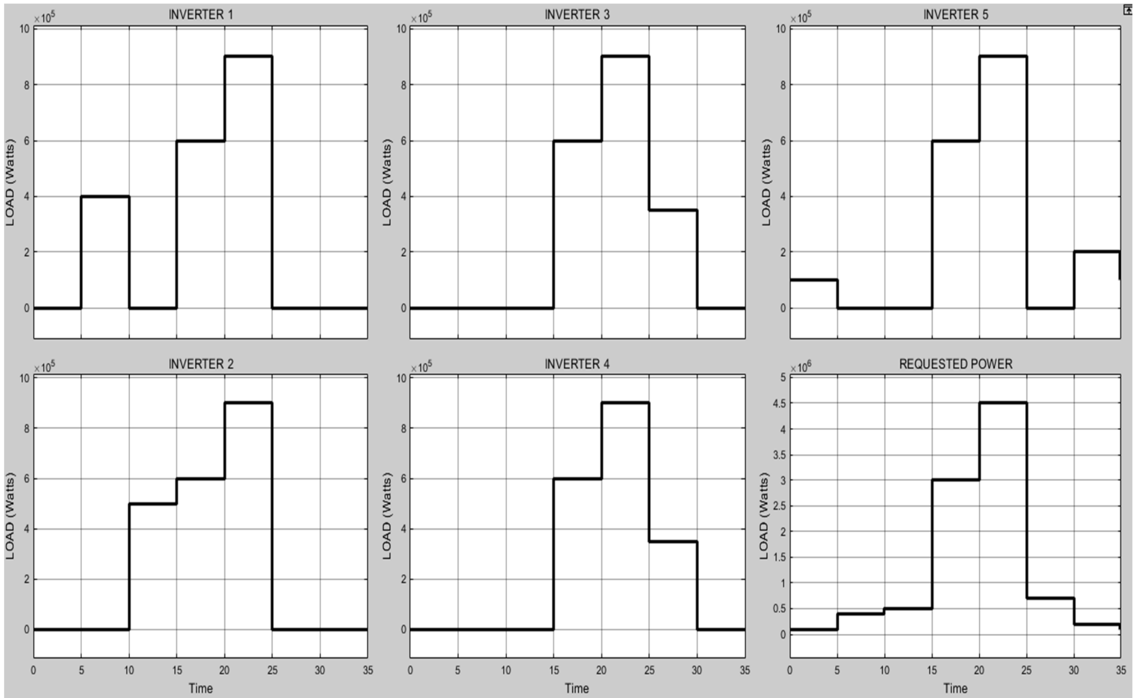

Figure 4. Simulation Results of Proposed inverter

The obtained results shows the sharing of the load by each inverter. The 0.1 MW load is first taken up by the inverter-5. Next, the inverter-1 takes up the next load 0.4 MW. The 0.5 MW is next taken up by the inverter-2. The next load 3MW is larger than 1.5 MW and so this load is divided by five and shared equally among all the five inverters. Hence each inverter supplies 0.6 MW and total power output from all the five inverters is equal to 3 MW.

Similarly, the next load 4.5 MW is also greater than 1.5 MW and hence, each inverter takes up 0.9 MW equally. The next load 0.7 MW is lesser than 1.5 MW and inverters 3 and 4 takes up 0.35 MW separately. The next load 0.2 MW is taken up by the fifth inverter.

A Conventional inverter employs the run-time minimisation algorithm and it does not employ the algorithm for the efficiency maximisation. This type of inverter is also developed and simulated in matlab and the efficiency of both the algorithm is checked and verified.

The conventional inverter do not concentrate on the load sharing based on efficiency and their algorithm runs to minimise run time.

The results are obtained for the input loads 0.1 MW, 0.4 MW, 0.5 MW, 3 Mw, 4.5Mw, 0.7MW and 2MW and is shown in figure.5.

VI. CONCLUSION

The results are obtained for the dynamically varying loads from the simulations of proposed algorithm and compared with the conventional algorithm. This comparison shows that the proposed method provides output with higher efficiency.

The elapsed time between the occurrences of two successive inverter failure depends on the factor called Mean Time Between Failures (MTBF). The failure will occur at different time for different inverters due to the uneven load sharing caused by variation in operational hours of inverters. So, the repairing and replacement of each inverters will occur at different time based on its running period. So, it ultimately leads to successive failure, repairing and replacement of inverters and this makes the customer's work to be hectic and difficult.

The service period or the life time of the inverter is around 25 years. If the load sharing is made uniform with the help of the multi master algorithm, then all the inverters operating hours would be same. The identical working hours of the inverters will cause all the inverters to retire at same time. So, this allows the customer to replace all the inverters at same time and hence the replacement of inverters at the same stretch makes it customer friendly.

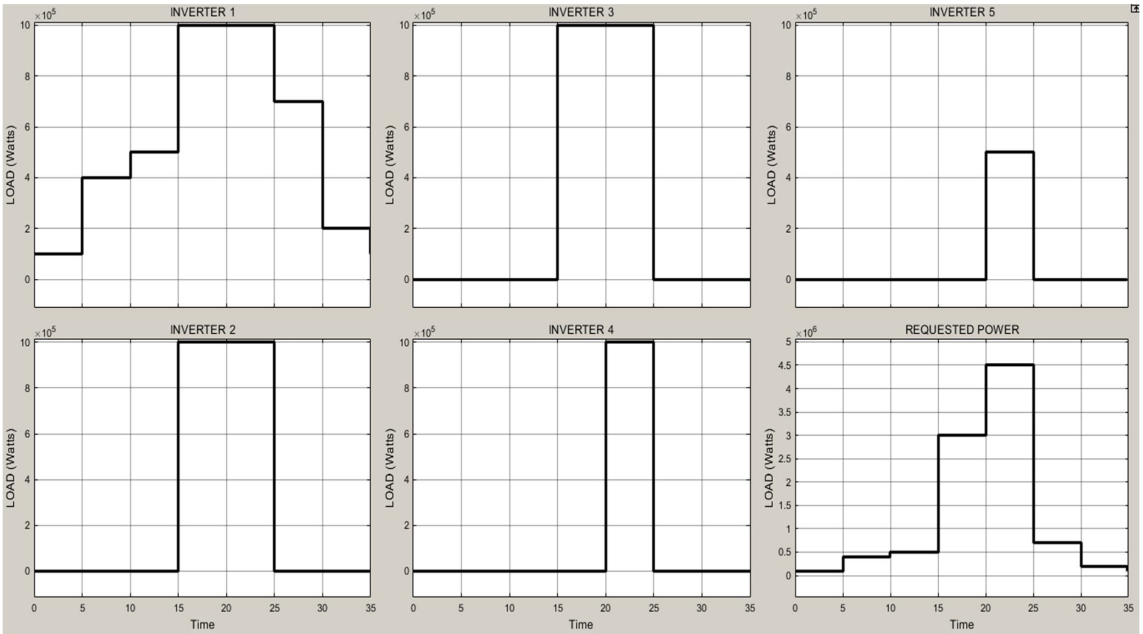

Figure 5. Simulation Results of Conventional Inverter

The maintenance of the inverters can be made easier using multi master algorithm. Since the operating hours are even, all the inverters can be shut down and maintained on the same time. Without the multi master operation, the inverters run time would be different and thus leading to maintenance of inverters to be done frequently.

The proposed algorithm for the multi-master inverter scheduling concentrates equally on both the objectives of run-time minimisation and efficiency maximisation. The simulation results obtained from the proposed model is found to have a higher efficiency than the model employing conventional algorithm.

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