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Novel load emulation technique for performance evaluation of isolated solar PV system under varying load conditions

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Solar Photo Voltaic (SPV) sources are widely used in present scenario of energy crisis for various applications including grid connected PV plants and grid isolated standalone applications. The performance of solar PV system is highly dependent upon the operating conditions of source and loads especially in standalone applications. The effect on various types of loads on standalone system can be easily analyzed at design stage and testing stage by using load emulation technique, where a virtual load is used to replace actual load, giving more flexibility and accuracy to loading conditions. Here a novel load emulator model is presented which can provide accurate variation in load power factor and THD compared to existing models. The converter decouples the current in to in phase and out of phase components and the in phase component can be regenerated. The model is simulated using MATLAB™ simulation and the results are validated by comparing with experimental results obtained by loading SPV inverter with actual load. Hence the proposed load emulator is very useful in design and development of application specific solar PV systems and also for performance analysis of such systems based on various standards.

Keywords: *Solar PV inverters, non-linear loads, low pf loads*

1.0 INTRODUCTION

Performance of renewable energy systems are highly dependent on the type of load applied. Many research works are being conducted to obtain the relationship between solar PV performance and different factors affecting the operation. When it comes to operating load conditions, most of the systems are designed for linear loads with unity power factor and from experimental analysis, it is found that they give lower performance when used for other non-linear and low pf loads. More over the back feeding due to load current distortion also reduces the power extraction from the source. In order to tackle this problem, the system performance under varying load conditions is to be studied and design is to be modified accordingly. Load emulation is an effective technique for this where actual load is replaced by a flexible system, either mechanical, hydraulic or electronic systems which can imitate the performance of the actual load and also regenerate the energy drawn from the system under test. Power electronic load emulation using back to back converters is the most modern development in this area, which find application in micro grid research also. Thus different types of loads can be obtained without the need for actual loads and large power dissipation [1-7].

In the present work, a novel emulation technique using power electronic converters is discussed

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for obtaining variable power factor and variable THD load conditions, without power dissipation in load components. It provides more accurate load characteristics in terms of power factor and THD, compared to the existing models and stores the power drawn in to battery bank. The working principle of the proposed converter, along with application in performance evaluation and design improvement of standalone solar PV systems are discussed. From simulation studies and experimental analysis, it is found that the efficiency and power quality of standalone Solar PV system varies considerably with changes in load conditions. Proposed emulation technique provides a flexible and accurate platform for obtaining variable THD and variable pf condition with very less losses compared to actual loading. Thus using this technique, the system performance can be improved at design stage based on the type of application and expected load type [8-12].

Section 2.0 explains the operation of solar PV inverters and section 3 gives a survey of different types of loads and the effect of low power factor (pf) and high Total Harmonic Distortion (THD) loads on the source. Section 3.0 and 4.0 explains the simulation and experimental studies with the results obtained giving a performance comparison of the inverter at different loads.

2.0 STAND ALONE SOLAR PV INVERTERS

Inverter is the most important component of AC Solar PV systems, where the DC power obtained from PV panel is converted in to line frequency AC. Stand-alone inverter or off-grid inverters are mainly used in remote areas or specific stand-alone applications like solar pumps and solar motors. They are designed at different power levels and different output waveforms depending on the application. For rural electrification and house hold use, the output waveform should be pure sinusoidal ideally. For solar PV based machine drives, the inverter output should be suitable for the machine operation.

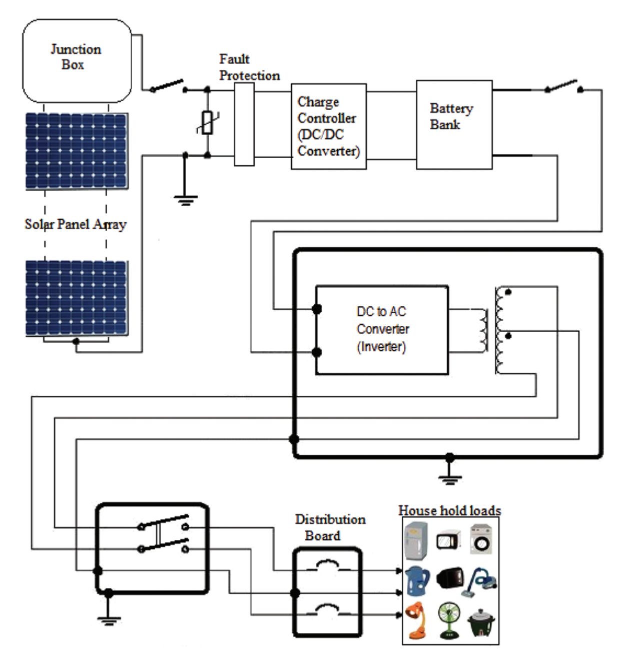

FIG. 1 STANDALONE SOLAR PV SYSTEM

As mentioned in the previous section, the inverter designed for a particular type of load may not give good performance at other conditions. Figure 1 shows the basic block diagram of a standalone Solar PV inverter. Many topologies and control techniques are being developed to obtain maximum performance for solar PV inverters.

3.0 TYPE OF LOADS

The type of load on solar PV system depends on the application. In grid connected systems, the load characteristics are regulated by grid operation. In the case of standalone systems, the load characteristics are purely determined by the devices connected at the output. Most of the systems in market are designed for linear loads with unity power factor and hence may not be adequate for applications with lower power factor or higher THD.

3.1 Effect of high THD loads

Total harmonic distortion denotes the extent to which the waveform deviates from pure sinusoid. Table 1 gives approximate THD levels caused by different types of loads especially in standalone renewable energy systems. Harmonic distortion affects the performance of renewable energy sources supplying the equipment. Some of the adverse effects are,

- Increase in core losses in transformer based systems
- Increase in current levels hence derating of equipment
- Increase in temperature in power electronic components and other unexpected locations. Hence reduces the life span of the equipment
- Interference with low voltage signals like control circuits and consequent malfunctioning.

TABLE 1

THD LEVELS OF STAND ALONE LOADS

Sl. No	Loads on standalone system	THD
1	Lighting Loads	5% to 25%
2	Motor Loads	5% to 30%
3	Heater Loads	2% to 10%
4	Pump Loads	5% to 10%
5	Other House hold appliances	5% to 25%

3.2 Effect of low PF loads

Power factor is an important factor determining the power quality and efficiency. Depending upon the application the load power factors varies considerably. In applications where magnetic fields are to be created, it will be more inductive in nature and hence increases reactive power requirement, reduces the system power factor. Other than inductive loads, non-linear loads also lowers the power factor due to the displacement power factor caused by distorted current. Displacement power factor can be defines as

The effective power factor will be contributed by both reactive component and displacement component. Low power factor load reduces the system efficiency and the components should be over rated to provide the required active power. The efficiency of power extraction from solar PV systems is also [8-12]

The power factor range of various solar PV based applications in standalone operation are shown in Table 2

TABLE 2

PF RANGE OF STAND ALONE LOADS

Sl. No	Loads on standalone system	Power factor
1	Lighting Loads	0.4 to 1.0
2	Motor Loads	0.17 to 0.85
3	Heater Loads	0.8 to 1.0
4	Pump Loads	0.7 to 1.0
5	Other House hold appliances	0.4 to 1.0

4.0 LOAD EMULATION TECHNIQUE

A load emulator is a controllable source or sink which can provide bidirectional power exchange with either a grid or another power electronic converter system [4]. Using load emulation, the operation of a system under various load conditions can be examined without the need for any electromechanical machinery or the actual load.

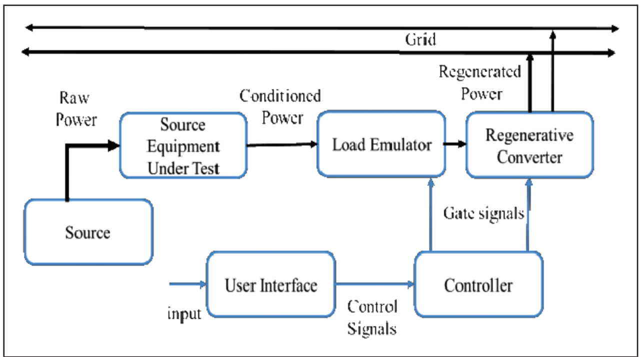

FIG. 2 BLOCK DIAGRAM OF THE PROPOSED MODEL

A generalized block diagram of regenerative load emulator is given in Figure 2. The load is actually a power electronic converter which draws the required current profile from the equipment under test. It then converts the power drawn in to AC and supplies to the grid [1-7].

In the proposed model, a new converter topology is adopted, where the load current is decoupled in to in phase and out of phase components in order to obtain accurate power factor variation.

The wave shape is modulated using PWM control to obtain the required THD. The power drawn by in phase converter can be regenerated using a regenerative converter.

5.0 SIMULATION AND RESULTS

The proposed load emulator model is implemented using Matlab/Simulink™ model. Figure 3 shows the overall simulation model for the proposed load emulator. The solar PV system is modelled using basic PV equation and Sinusoidal PWM modulated inverter [11-15]. The required load pf and required VA are the inputs to the controller. The controller algorithm calculates the required PWM signals for each branch depending upon the input values as shown in figure

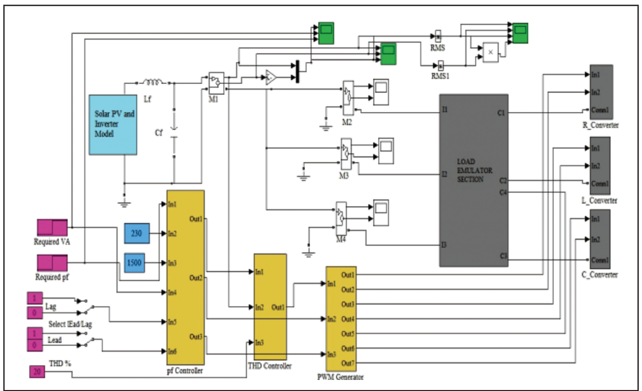

FIG. 3 OVERALL SIMULATION DIAGRAM OF PROPOSED LOAD EMULATOR MODEL

The above shown simulation model was evaluated for different input conditions and is found to provide the required wave forms as shown in Figure 4 and 5.

In Figure 4, the input command for Power are, P_1 = 800 VA, At t=0

P_2 = 1400 VA, at t=0.04

Input command for Power factor pf 1= 1, At t=0

pf 2= 0.6, at t=0.08

The emulator waveforms are found to follow these conditions

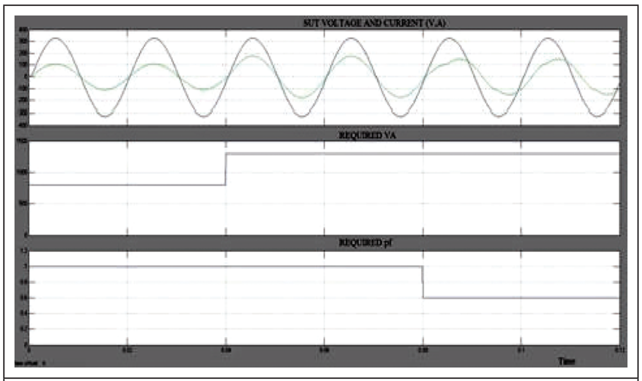

FIG. 4 EMULATOR OUTPUT WAVEFORMS AND INPUT COMMANDS FOR VARIABLE POWER FACTOR

Similarly THD can also be controlled as per requirement. Figure 5 shows the chopped waveform of emulator when THD is increased from 5% to 30%.

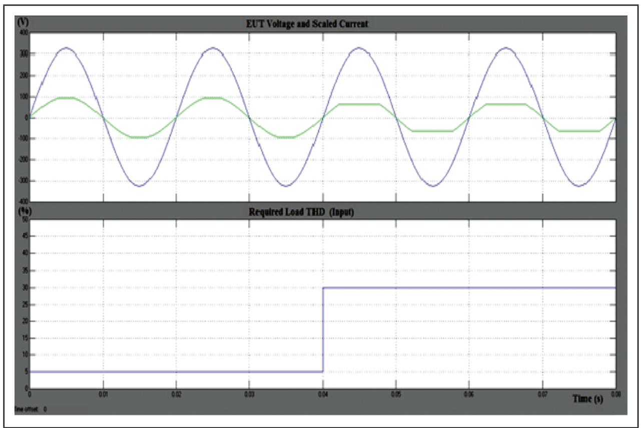

FIG. 5 EMULATOR OUTPUT WAVEFORMS AND INPUT COMMANDS FOR VARIABLE THD

Using this model, a study is conducted on solar PV inverter model for the performance variation under various load conditions. The results obtained and observations can be summarized as follows:

- Inverter efficiency is found to decrease as power factor varies from unity to 0.5 lagging as shown in Figure 6.
- Efficiency is found to decrease as THD increases as shown in Figure 7.
- The proposed load emulator can provide different THD and loading conditions as per the requirement to study the system performance.

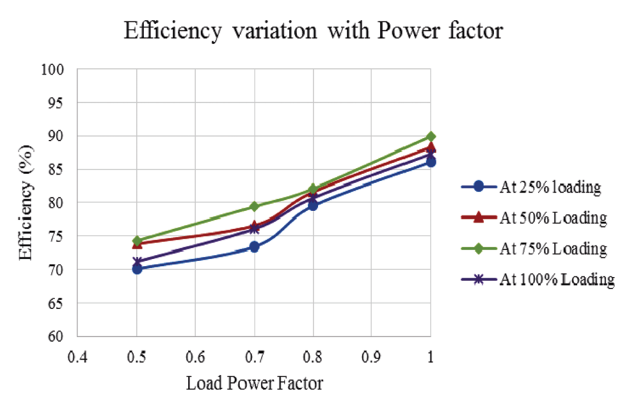

FIG. 6 PERFORMANCE ANALYSIS AT VARIOUS LOAD POWER FACTORS

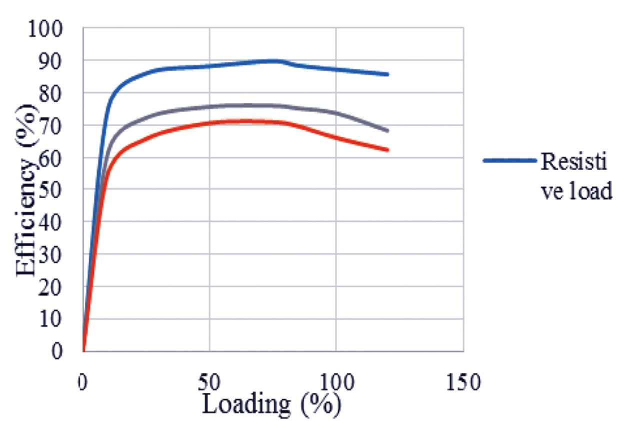

FIG. 7 PERFORMANCE ANALYSIS AT VARIOUS LOAD THD

- Using the proposed model, the converter design can be modified at development stage itself based on the expected load pf and THD. The performance analysis is made easy without the need of actual loads.

6.0 COMPARISON WITH ACTUAL LOADING

In order to validate the results obtained using load emulator, a performance analysis of solar PV inverter was conducted using some dissipative load setup as shown in Figure 8. The analysis is done under constant battery voltage condition where battery input is given using a controllable DC source. 3 kVA solar PV inverter of 48 V rated DC input is the system under test. AC to DC conversion under various load conditions is examined.

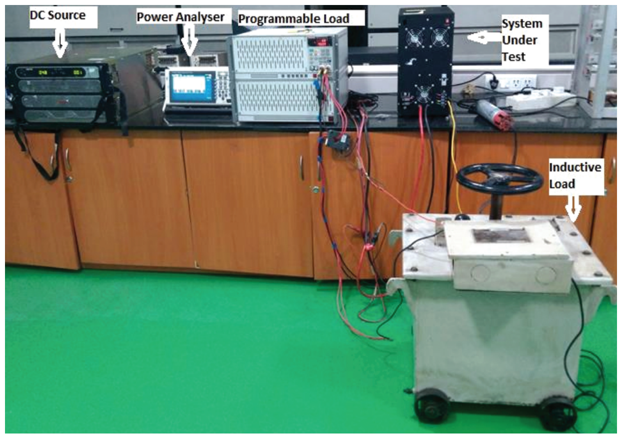

FIG. 8 EXPERIMENTAL SETUP FOR VALIDATION OF SIMULATION RESULTS

Resistive load is applied using variable resistive load. One high THD load is obtained by chopping the current wave form in the programmable load and inductive load is obtained using auto transformer. The results are shown in Table 3 and they are found to be in line with the results obtained by simulation of proposed load emulator.

TABLE 3

EXPERIMENTAL RESULTS

Loading (%)	Efficiency at linear Unity pf (%)	Efficiency at 0.8 pf (%)	Efficiency at 25% THD load (%)
10	75.4	71.2	64.2
25	86.1	82.5	74.5
50	88.3	84.6	76.6
75	89.9	82.1	77.1
100	88.5	81.8	76.8
120	87.3	79.7	75.7

7.0 CONCLUSIONS

Using the proposed method of variable PF and variable THD load emulation, different types of load characteristics can be realised easily using a single converter. The simulation results of proposed model of load emulator are found to be matching with the results obtained by experimental analysis using actual load.

But unlike actual loading, the energy drawn by the emulator can be regenerated easily using a regenerative converter. Hence the losses in testing and validation process can be reduced to a great extent. Accurate emulation of load characteristics helps in improving system design, performance analysis, Research and development etc. especially in case of renewable energy sources. Load emulators can be also used as virtual loads for load balancing in micro grids.

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