# Load Emulators for Testing of Power Supplies - A Review

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*All newly designed power electronic equipments are to be tested as per the standards, so as to verify the response of the equipment under various load conditions. For this, different linear, non-linear and dynamic loads are to be applied to the equipment in accordance with the applications. Load emulation is the process by which the actual load is replaced by a flexible system which can mimic the characteristics of the actual load. A regenerative operation can be implemented in power electronic emulators. Thus by using load emulators for testing, the energy lost in testing of equipments can be reduced to a great extent. Here a review of various types of load emulators is presented which are intended for various types of applications along with some experimental results obtained in various research studies.*

**Keywords**: *Load emulation, non-linearity, power regeneration, Phase Locked Loop*

## 1.0. INTRODUCTION

In electrical testing laboratories, various types of loads are required based on the testing standards especially for renewable energy systems. Typically resistive, inductive and capacitive loads with various power factors and loading are required along with machine dynamic characteristics for machine loads. In the case of solar and wind power applications, it becomes necessary to test the equipment behaviour for loads inducing harmonics because of wide spread use of solid state devices.

Load emulator is a controllable source or sink which can provide bidirectional power exchange with either a grid or another power electronic converter system [1]. 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. Load emulators developed throughout the years include power system load emulators, machine load emulators, mechanical load emulators etc. The most recent works in the field of emulators were carried out in electrical machine emulation and renewable energy studies[1-2]. Power system loads were emulated using analog circuits which exhibit non linear behavior [4-5]. The possibilities of a load emulator using purely power electronic converter were explained in recent years [6]. Machine loads can be emulated using load models in suitable controllers[13]. The studies in the last decade were mainly about mechanical load emulation using generator motor sets [10-12]

## 2.0. ADVANTAGES OF LOAD EMULATION

In order to test inverters and equipments for renewable energy sources, it is often difficult to verify the operation for different types of linear, non-linear and dynamic load conditions.

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For example according to IEC 61683 standards testing of photovoltaic systems, it shall be tested for 10%, 25%, 50%, 75%, 100% and 120% of the inverter rating and power factors from 0.25-0.95 for reactive loads. The inverters shall also be tested for loads with non-linearity with Total Harmonic Distortion (THD) ranging from (80±5)% down to (20±5)% of the inverter rating.

Conventionally, for testing of power equipments, resistive inductive and capacitive load are evaluated by using an electronic load. The power drawn by the load is dissipated in the load which causes energy wastage and also results in temperature rise. Emulation is the process of controlling a power electronic or electro mechanical system so that it draws or supplies current as per the required load condition. A sample load profile to be tested according to IEC 61683 is shown in Figure 1.



FIG. 1    GRAPH SHOWING THE LOAD PROFILE TO BE TESTED FOR INVERTER WITH FRACTION OF FULL LOAD AGAINST TIME.
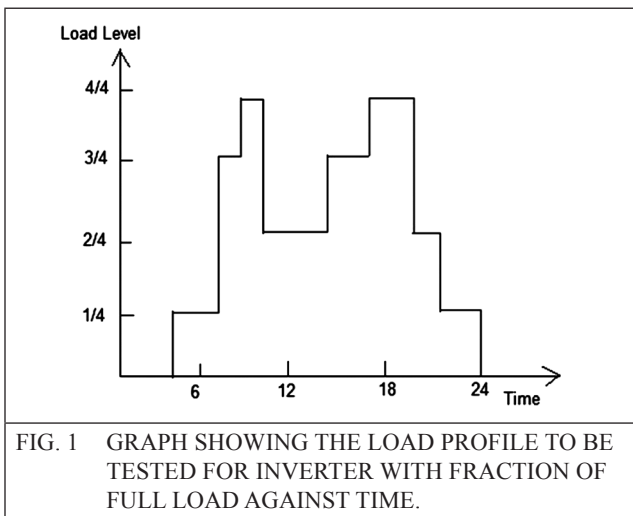
## 3.0. POWER ELECTRONIC LOAD EMULATORS

By power electronic load emulation, the entire load is replaced by pure power electronic converters. Here the most important part is the control algorithms which generate the required reference values and the gate signals for the emulator. One of the advantages of power electronic emulators is that the power drawn by the converter can be regenerated and supplied back to the mains. It simply consists of a back to back converter

inverter set and suitable controllers [4]. The block diagram of a regenerative load emulator is shown in Figure 2. Other than resistive inductive and capacitive load conditions, non-linear loads, machine load models, power system loads etc can be implemented using power electronic emulator.



FIG. 2    GENERAL BLOCK DIAGRAM OF A REGENERATIVE LOAD EMULATOR
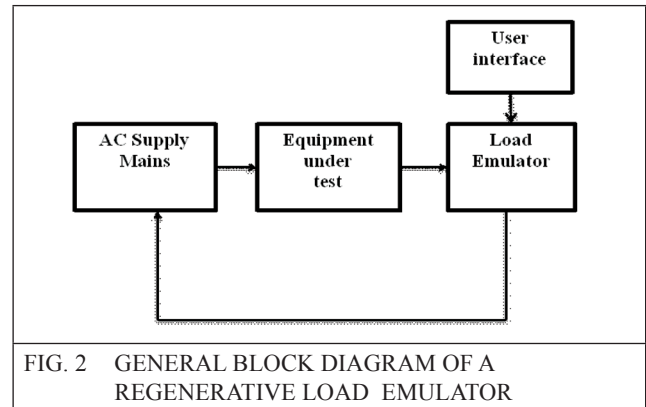
### 3.1. Power system load emulation

Power system emulators can be used for studying and testing of equipments connected to grid under various load conditions, stability issues etc. In 2012 a two stage grid connected emulator system was designed which was mainly intended for power system load emulation. A 5kW prototype was developed consisting of an active rectifier with a dual active bridge [3]. Another attempt was a one cycle controlled 3-phase rectifier for power system load emulation [5]. In the case of regenerative emulator with back to back converter as describes in previous section a 3 phase 6 leg converters along with filter inductance, and capacitance can be used as shown in Figure 3. The gate signals are applied according to the required load conditions.



FIG. 3    CONVERTER CIRCUIT FOR LOAD EMULATION
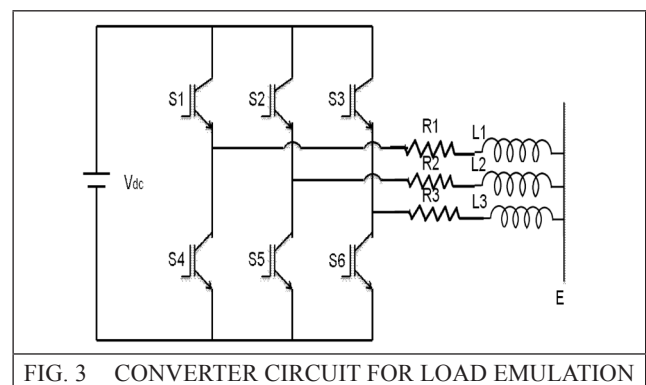
As per the figure shown, the dynamic equation for the power system load can be represented as

$$V_{abc} = (L\frac{d}{dt} + R)I_{abc} + E_{abc} \qquad ....(1)$$

Where

$$V_{abc} = [V_a + V_b + V_c]^T \qquad ....(2)$$

$$I_{abc} = [I_a + I_b + I_c]^T \qquad ....(3)$$

$$E_{abc} = [E_a + E_b + E_c]^T \qquad ....(4)$$

Where,

V= Terminal Voltage

i= Current

Suffix a, b and c represents three phases.

Assuming balanced three phase voltage it can be transformed in to dq axis obtaining dynamic equations as shown below. In order to track di/dt, the controller should be of fast response.

$$V_{de} = Ri_{de} + L\frac{di_{de}}{dt} - \omega Li_{qe} + E_{de}] \qquad ....(5)$$

$$V_{qe} = Ri_{qe} + L\frac{di_{qe}}{dt} - \omega Li_{de} + E_{qe}] \qquad ....(6)$$

Where,

R= Winding resistance

L= Winding inductance

Suffix d and q represents d axis and q axis components respectively.
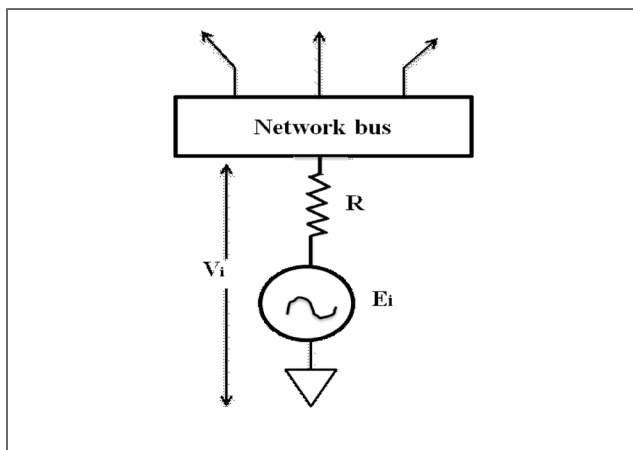


FIG. 4    SIMPLIFIED EQUIVALENT CIRCUIT FOR POWER SYSTEM EMULATION.

Emulation of power systems can be done by using analog circuits to implement load models of power injection, load power flow etc. Bus node voltages and branch currents can be obtained when emulated systems settles in equilibrium. A simplified equivalent circuit for power system emulation is shown in Figure 4.

The analog circuit can be implemented using an Operational Transducer Amplifier (OTA) based integrator circuit as shown in Figure 5. The behavior of OTA is highly non-linear in nature which is actually a voltage controlled current source whose gain is dependent on external biasing current. A set of differential equation for power system load emulation can be implemented using the circuit shown in Figure 5. The amplifier based emulator can also be used for stability analysis of power system loads [7- 8].
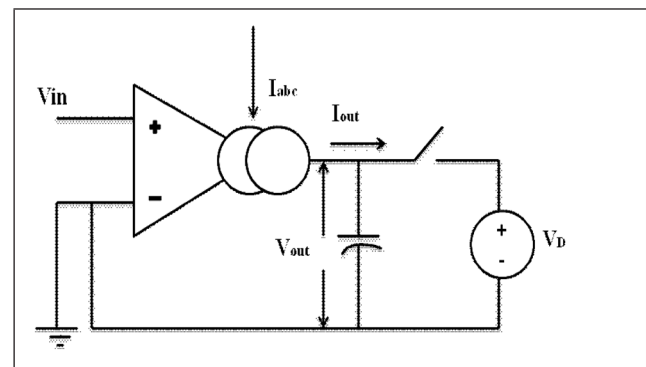


FIG. 5    AMPLIFIER BASED ANALOG CIRCUIT FOR POWER SYSTEM LOAD EMULATION.

## 3.2. Machine load emulation

Industrial loads involve various kinds of machine loads which are largely dominated by induction machines. Emulation of machine loads will provide a more flexible platform for testing of power converters and inverters for electrical machines. The concept of 'virtual machine, was introduced in 1998 [13] where the elctromechanical load was emulated using power electronic converter. The main concept is that the current drawn should follow the motor load current. So here a motor model is used to generate the reference value of the required current. The model and controller operation is implemented using DSP controller.

The inverter voltage is sample and given to the motor model.

The sampling time should be carefully chosen depending upon the switching frequency of PWM inverter so that data is not lost. The model can be implemented in dq reference frame. A PLL is implemented after sampling to obtain the frequency and angle for dq transformation reference. The induction motor model is first order non-linear equation of the form

$$\frac{d\bar{y}}{dt} = A.\bar{y} + b \qquad ....(7)$$

$$\bar{y} = [i_{ds} \quad i_{qs} \quad i_{dr} \quad i_{qr}] \qquad ....(8)$$

Where, ids, iqs are d axis and q axis components of stator current and idr and iqr are the d axis and q axis components of rotor current.

Since iterative method is required for solving the equations, fast algorithms can give better results for dynamic emulation. From the values obtained from PLL, the dq reference can be calculated by,

$$\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\omega t & \sin\omega t \\ -\sin\omega t & \cos\omega t \end{bmatrix} \begin{bmatrix} 1 & \dfrac{-1}{2} & \dfrac{-1}{2} \\ 0 & \dfrac{\sqrt{3}}{2} & \dfrac{-\sqrt{3}}{2} \end{bmatrix} ..(9)$$

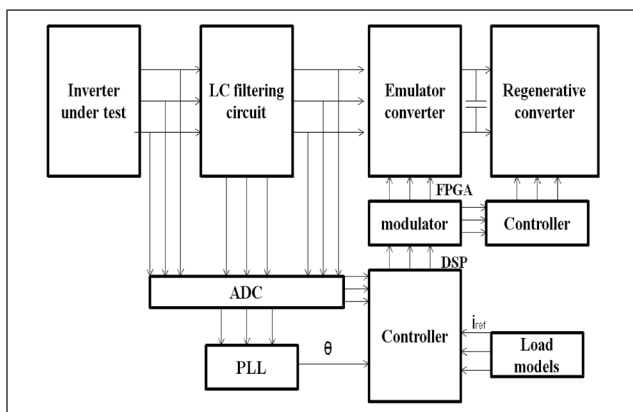where, vds and vds are the d axis and q axis voltage of stator.



FIG. 6    FPGA- DSP BASED POWER ELECTRONIC
            LOAD EMULATOR

An LCL filter can be implemented to remove switching frequency harmonics. For real time dynamic simulation, the processing time of DSP instruction should be of the order of nano seconds. So FPGA is a better option for high speed operation. Since it is not mathematically oriented, a combination of FPGA and DSP can give desirable results [6]. A circuit diagram for emulation using FPGA and DSP platforms is shown in Figure 6.

### 3.3. Mechanical Load Emulation

The concept of load emulation by replacing actual load was first implemented in mechanical systems. The interaction between the electric drive, the motor, and the mechanical load is an important consideration when studying and designing an electrical drive system. The motor, drive and load should be compatible with each other for smooth operation. Mechanical load emulators are implemented mostly using Generator motor set so as to obtain dynamic characteristics. The output of the equipment is used to drive a motor generator set and the generator is electrically loaded [10]. generalised diagram is shown in Figure 7.
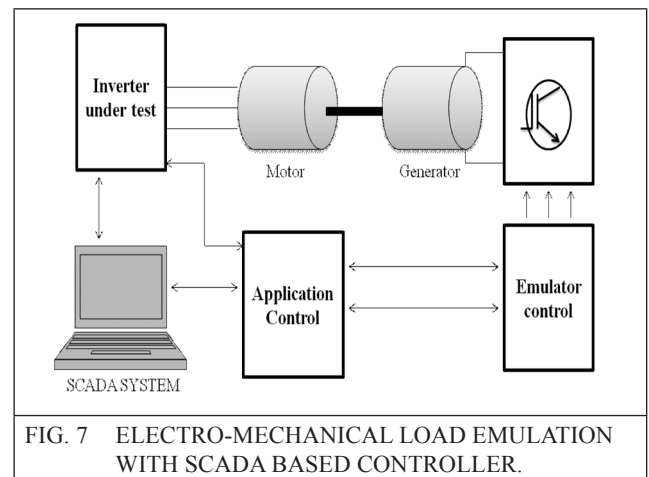


FIG. 7    ELECTRO-MECHANICAL LOAD EMULATION
            WITH SCADA BASED CONTROLLER.

The motor dynamics are implemented by controlling the torque and speed of the generator by varying the current drawn by the generator.

We have,

$$V_T = E_g - I_a R_a = \omega k_b - I_a R_a \qquad ....(10)$$

$$T = k_b I_a \qquad ....(11)$$

Where,

VT = Terminal voltage of generator

Eg = Generated voltage

Ia = Armature current of generator

Ra = Armature Resistance of generator

ω = Angular speed

T  = Developed Torque of the motor

According to the type of load to be emulated, the relation between V and I is implemented in the controller.

For example, in the case of pump load,

$$T = k\omega_m^2 \Rightarrow I = f(V_T) = kV_T^2 \qquad ….(12)$$

Dynamic mechanical loads as per requirements can be easily simulated using a programmable dynamometer setup. Here a real time controller is also implemented in order to implement the generator control as per the dynamic load requirement [11- 12].

The control of the load machine is to be done in such a way that the desired linear or nonlinear relation is obtained between the shaft angular speed and the electrical driving machine torque. Intelligent control algorithms can be implemented in this controller for the experimental validations of the algorithms. The problem of controlling the dc machine to behave as a mechanical load is the addition of unwanted dynamic effects which affects the accuracy of the modeled load. This can be solved to some extend by including suitable compensation in the control loop. The comparison of parameters achieved in inverter testing with electronic load and regenerative load emulator is presented in Table 1.

The plot of efficiency of back to back converter against fraction of rated load is shown in the graph below. Maximum efficiency is obtained between 60 and 70% of rated load. Where as in the case of electronic load the efficiency is always zero since entire power is dissipated in the load.

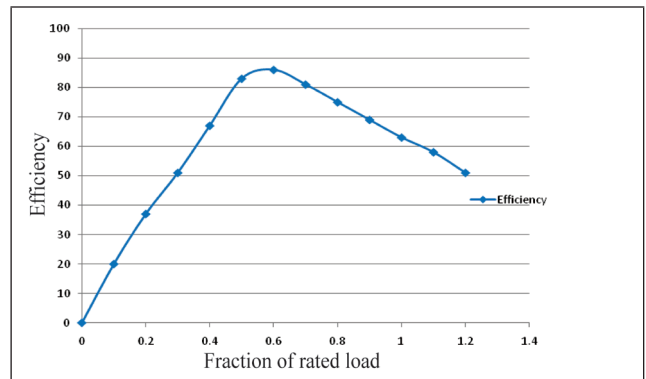| TABLE 1 | | |
|---|---|---|
| COMPARISON OF ELECTRONIC LOAD AND REGENERATIVE LOAD EMULATOR | | |
| **Parameter** | **Electronic Load** | **Regenerative load emulator** |
| Efficiency | 0% | 85% - 95% |
| pf | 0.85-1 | 0.25-1 |
| Loading | 25% - 120% | 5% - 120% |
| THD | Hard to control | 80±5% - 20±5% |
| Power range | Higher power rating causes more energy loss | Can be upgraded according to requirement |



FIG. 8    EFFICIENCY VERSUS LOAD GRAPH FOR BACK TO BACK CONVERTER

## 4.0.  INDUSTRIAL STATUS

Currently various firms across the world are developing different types of electronic loads for industries, equipment testing and research and development according to customer requirements. DC loads are widely available with various customized features from various manufacturers and designer. DC electronic loads are designed for testing multi-output AC/DC power supplies, DC/DC converters, chargers, batteries, adapters, and power electronic components. The system uses DSP technology to simulate non-linear loads using a unique allowing realistic loading behavior. But in all these systems, the energy drawn is dissipated in the load resulting in wastage.

Similar is the case with AC loads. It is very difficult to obtain very low values of power factors for testing requirement since the power drawn is

dissipated in the load resistances. AC loads with varying power factor have been developed by Chroma ATE, Ametek, Prodigit, NHR labs etc. The systems provide flexible load solutions but are not of regenerative nature.

## 5.0. CONCLUSIONS

Use of load emulators for electrical equipment testing will provide a more flexible platform for obtaining variety of load conditions according to the applications and testing standards. The losses during testing can be minimized by using regenerative converters. The can be used for study of behavior of supply units for machine load, power system load, SMPS devices etc. The same system can be made to behave as different types of loads to obtain a universal load in such a way that the system can be easily upgraded to higher rating.

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