Montazer-Ghaem Gas Unit Synchronous Generator's Parameters Identification Using SSFR Tests

M. Pourgholi  V.J.Majd  M.R. Aghamohammadi

Abstract: Accurate generator modeling allows for more precise calculation of power system control and stability limits. In this paper a procedure using a set of measured data from Standstill Frequency Response (SSFR) test on Montazer-Ghaem gas power plant’s synchronous generator is used to obtain synchronous machine parameters. A novel approach is used to find d-axis which is different from standard SSFR scheme which can save the time in doing SSFR tests. Hook-Jeeves method is used for optimization purpose. The test procedure and identification results are reported.

Keywords: SSFR, Synchronous generator, Parameter identification

I. INTRODUCTION

Stability analysis is one of the most important tasks in power system operations and planning. Synchronous generators play a very important role in this way. A valid model for synchronous generators is essential for a reliable analysis of stability and dynamic performance. Almost three quarters of a century after the first publications in modeling synchronous generators, this subject is still a challenging and attractive research topic.

Two axis equivalent circuits are commonly used to represent the behavior of synchronous machines. The direct determination of circuit parameters from design data is very difficult due to intricate geometry and nonlinear constituent parts of machines. So several tests have been developed which indirectly obtain the parameter values of equivalent circuits. The stand still Frequency Response (SSFR) test has been widely accepted for extraction synchronous machine parameters. The SSFR method has the following advantages [1]:

1) It is easy to implement at the factory or during outages for routine maintenance without risk to the machine, since the tests involve very little power.
2) The ready availability of powerful computer tools have eased the data logging and analysis procedures.
3) Unlike the ANSI-standardized short-circuit test, the SSFR approach can simultaneously provide the equivalent circuits for both direct and quadrature axes, and at the present time, seems the most appropriate for modeling the machine behavior for stability analysis.

Frequency response testing of electrical machines as a means of determining their parameters was introduced by [2] but the main thrust for the current work stems from the comprehensive study of the problem initiated by EPRI which culminated in the workshop in 1981 [3].

Reference [4] presented results of frequency response tests carried out on a 555MVA machine, with limited frequency range of 0.01 to 10 Hz but this was sufficient to identify a third order model for the machine. Authors in reference [5] presented results for third order models for several machines introducing the concept of unequal mutual in the direct axis. In [6] proposed a new third order model claiming it as an improvement on the limited second order model. In [7] offered a recursive least squares algorithm with a frequency dependent weighting function to accentuate particular frequency ranges as an aid to the identification of the time constants. In [8] reported on the virtues of a “three transfer function approach” implying that such a model had not been considered before. Many of their comments related to a comparison of second and third order models, seeking to validate their extension to their new third order model. Numerical curve-fitting methods were used in all of the above papers.

In this paper an experience with SSFR test on Montazer-Gaem gas unit generator is presented and uses Hook and Jeeves optimization method for curve fitting purpose.

II. MACHINE MODELING

The structure of the synchronous machine model used in this study is a standard second order model with one damper in the d-axis and two dampers in the q-axis given in Fig. 1 [9]. Degree of the applied model is selected based on synchronous
generator type, rotor structure and IEEE-Std-1110 considerations. The equations of generators are as stated in [2]. Definition of the parameters is listed in table (1) and some relations between parameters are listed in Appendix.

![Generator Diagram](image1)

**Fig.1** Synchronous Machine Equivalent Circuits According to 2-2 Model of IEEE Std 1110

![Generator Diagram](image2)

**Fig.1** Synchronous Machine Equivalent Circuits According to 2-2 Model of IEEE Std 1110

![Generator Diagram](image3)

**Fig.1** Synchronous Machine Equivalent Circuits According to 2-2 Model of IEEE Std 1110

Table (1) synchronous generator parameters definition

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Parameters definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_l$</td>
<td>Armature leakage reactance</td>
</tr>
<tr>
<td>$X_{ad}, X_{aq}$</td>
<td>Armature to rotor mutual reactance</td>
</tr>
<tr>
<td>$X_{d}$</td>
<td>d- axis differential leakage reactance</td>
</tr>
<tr>
<td>$X_{fd}$</td>
<td>Field winding leakage reactance</td>
</tr>
<tr>
<td>$X_{ld}, X_{lq}, X_{f}$</td>
<td>Damper winding leakage reactance</td>
</tr>
<tr>
<td>$R_a$</td>
<td>AC Armature resistance</td>
</tr>
<tr>
<td>$R_e$</td>
<td>Field winding resistance</td>
</tr>
<tr>
<td>$R_{d}, R_{q}, R_{f}$</td>
<td>Damper winding resistance</td>
</tr>
<tr>
<td>$Z_d$</td>
<td>d- axis operational impedance</td>
</tr>
<tr>
<td>$Z_q$</td>
<td>q- axis operational impedance</td>
</tr>
<tr>
<td>$G(s)$</td>
<td>standstill armature to field transfer function</td>
</tr>
<tr>
<td>$Z_{st}(s)$</td>
<td>standstill armature to field transfer impeda</td>
</tr>
<tr>
<td>$V_d$</td>
<td>direct axis armature voltage</td>
</tr>
<tr>
<td>$V_f$</td>
<td>field voltage</td>
</tr>
<tr>
<td>$V_q$</td>
<td>quadrate axis armature voltage</td>
</tr>
<tr>
<td>$N_a$</td>
<td>effective number of turns on one phase on armature wining</td>
</tr>
<tr>
<td>$N_{fd}$</td>
<td>effective number of turns on field winding</td>
</tr>
</tbody>
</table>

**III. TEST PROCEDURE**

The SSFR test is categorized in off-line tests so machine shall be shut down, disconnected from its turning gear and electrically isolated. Also all connection to the field should be taken off, this can be done by removing the brush gear or, in the case of a brushless exciter, electrically disconnecting the complete exciter from the generator field winding.

This test consists of two steps, one for d-axis and another for q-axis. For each step, by positioning the rotor align with d or q axis and temporarily connecting the power amplifier as in table (2) the tests are performed.

![Test Leads Connection](image4)

**Fig.2** Test leads connection to stator bus

![Positioning Rotor](image5)

**Fig.3** Positioning rotor align with q- axis tests

Reducing or eliminating the effect of contact resistances is very important to the accuracy of the measurements, particularly for the armature winding. The armature current metering shunt should be bolted directly to the conductor in the isolated phase bus, as close to the generator terminals as possible, also conducting grease should be used to enhance the contact. Fig. 2 shows the proper connection of the test leads for such devices.

For aligning the rotor with the q-axis, a power amplifier is temporarily connected as in Fig 3. A signal generator tuned on 100 Hz and 10 amperes drives the amplifier. Then the induced field voltage is measured with an oscilloscope. The generator rotor is slowly turned until a null induced field voltage is achieved. This situation indicates quadrate-axis of the synchronous machine. Fig.4 shows test circuit for finding q-axis position and Fig.5 shows visionary proof for minimum induced voltage in rotor when connecting stator winding as like as Fig.3.
Fig. 4) Test circuit for finding q-position

Table (2) Standstill Frequency Response Test

<table>
<thead>
<tr>
<th>No.</th>
<th>Measurement</th>
<th>Test Diagram</th>
<th>Measured Value</th>
<th>Relationships</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>q-Axis operational Impedance $Z_q(s)$</td>
<td></td>
<td>$U_{\text{stator}}$</td>
<td>$U_{\text{rotor}(\text{about 0})}$</td>
</tr>
<tr>
<td>2</td>
<td>d-Axis operational Impedance $Z_d(s)$</td>
<td></td>
<td>$U_{\text{stator}}$</td>
<td>$U_{\text{rotor}(\text{max})}$</td>
</tr>
<tr>
<td>3</td>
<td>Standstill armature to field transfer function $sG(s)$</td>
<td></td>
<td>$U_{\text{stator}}$</td>
<td>$I_{\text{rotor}}$</td>
</tr>
<tr>
<td>4</td>
<td>Standstill armature to field transfer impedance $Z_{af0}$</td>
<td></td>
<td>$U_{\text{rotor}}$</td>
<td>$I_{\text{rotor}(\text{about 0})}$</td>
</tr>
</tbody>
</table>
In this paper a novel approach is used to obtain d-axis which is different from standard SSFR scheme [1]. For this purpose, after finding q-axis, by keeping rotor position the armature phase winding connection is changed as illustrated in table (2). In this situation the rotor is aligned with d-axis. With using this novel method, the d-axis could be found as illustrated in table (2). In this situation the rotor is aligned with d-axis. Armature phase winding connection is changed as illustrated in this purpose, after finding q-axis, by keeping rotor position the armature phase winding connection is changed as illustrated in table (2). In this situation the rotor is aligned with d-axis. With using this novel method, the d-axis could be found as illustrated in table (2).

For performing SSFR tests, considering the test circuits illustrated in table (2), the following tests are carried out.

For each test, the frequency of the provided sin wave signal by the signal generator is changed over the range of 0.1Hz to 1000 Hz. Then for each frequency, the magnitude and phase of \( \Delta e_q, \Delta i_q, \Delta e_d, \Delta i_d \) and \( \Delta i_{fd} \) are measured.

Approximately 10 test points, logarithmically spaced per decade of frequency, is a satisfactory measurement density.

\[ N_{fd} = \frac{1}{sL_{ad}(0)} \lim_{s \to 0} \left[ \Delta e_{fd}(s) \right] \]

6) Calculate the field resistance referred to armature winding.

\[ R_{fd} = \lim_{s \to 0} \left[ \frac{\Delta i_{fd}(s)}{\Delta i_{q}(s)} \right] \frac{N_{fd}}{N_{a}} \]

7) Define an equivalent circuit structure for the d and q axes.

8) Use the Hook-Jeeves optimization technique to find the best value for generator parameters which provide the best fits for \( L_d(s) \) and \( L_q(s) \) and \( sG(s) \)

9) Measure the fields winding resistance, convert it to the desired operating temperature, and refer it to the stator.

\[ R_{fd-o} = \frac{234.5 + \theta}{234.5 + T_f} \frac{3}{2} \frac{N_{a}}{N_{fd}} \]

Where \( R_{fd} \) is the field resistance measured at field terminal and \( T_f \) is the average field winding temperature in °C during the measurement. Substitute this value for \( R_{fd} \) in the equivalent circuit. For the field winding materials other than copper, appropriate values of temperature coefficient should be used. (234.5 for copper).

\[ N_{fd} = \frac{1}{sL_{ad}(0)} \lim_{s \to 0} \left[ \Delta e_{fd}(s) \right] \]

IV. IDENTIFICATION PROCEDURES

The procedure for extracting d and q-axes parameters from SSFR tests can be summarized as follows [12]:

1) Use the best available estimation for armature leakage inductance \( L_d \); it could be valued supplied by manufacturer.

2) Using the measured values, by means of Fourier transform the RMS value of the main wave associated with each measured quantities and corresponding to each frequency are obtained.

3) Based on the equations for \( Z_d \) and \( Z_q \) mentioned in table (2) and using RMS values for the measured quantities, the value for \( Z_d \), \( Z_q \) and \( G(s) \) are obtained corresponding to each frequency.

4) Obtain \( L_d(0) \) and \( L_q(0) \) which are low- frequency limit of \( L_d(s) \) and \( L_q(s) \) and then determine

\[ L_{ad}(0) = L_d(0) - L_d \]  \hspace{1cm} (1)

\[ L_{aq}(0) = L_q(0) - L_q \]  \hspace{1cm} (2)

5) find the field to armature turns ratio \( N_{fd}/N_a \) using the armature to field transfer impedance \( Z_{adf}(s) \)

\[ \frac{N_{fd}}{N_a} = \frac{1}{sL_{ad}(0)} \lim_{s \to 0} \left[ \Delta e_{fd}(s) \right] \frac{\Delta i_{fd}(s)}{\Delta i_{q}(s)} \]  \hspace{1cm} (3)

1- Start with an arbitrarily initial point \( X_k=[x_1, x_2, ..., x_n]^T \), called the starting base point and prescribed step lengths \( \Delta x \) in each of the coordinate directions \( u_i \), \( i=1,2,...,n \). set \( k=1 \).

2- Compute \( f_k = f(X_k) \). Set \( i=1 \) and define new variable with initial value set as, \( Y_{k_0} = X_k \) and start the exploratory move as stated in step 3.

3- The variable \( x_j \) is perturbed about the current temporary base point \( Y_{k,i} \) to obtain the new temporary base point as follows:
This process of finding the new temporary base point is continued for \( i=1, 2, \ldots \) Until \( x_2 \) is perturbed to find \( Y_{k,n} \).

4- If the point \( Y_{k,n} \) remains same as the \( X_k \), reduce the step lengths \( \Delta x_i \) (say by a factor of two), set \( i=1 \) and go to step 3. If \( Y_{k,n} \) is different from \( X_k \), obtain the new base point as

\[
X_{k+1} = Y_{k,n}
\]  

and go to step 5.

5- With the help of the base points \( X_k \) and \( X_{k+1} \) establish a pattern direction \( S \) as

\[
S = X_{k+1} - X_k
\]  

and find a point \( Y_{k+1,0} \) as

\[
Y_{k+1,0} = X_{k+1} + \lambda S
\]  

The point \( Y_{k+1,0} \) is the temporary base point obtained from the base point \( X_k \) by perturbing the \( i \)th component of \( X_k \).

Where \( \lambda \) is the step length which can be taken as 1 for simplicity.

6- set \( k=k+1 \), \( f_k = f(Y_{k,0}), i=1 \) and repeat step 3, if at the end of step 3, \( f(Y_{k,n}) < f(X_k) \), we take the new base point as \( X_{k+1} = Y_{k,n} \), and go to step 5. On the other hand if \( f(Y_{k,n}) \geq f(X_k) \), set \( X_{k+1} = X_k \), reduce the step length \( \Delta x_i \), set \( k = k+1 \) and go to step 2.

7- The process is assumed to be converged whenever the step lengths fall below a small quantity \( \varepsilon \). Thus the process is terminated if

\[
\max_i (\Delta x_i) < \varepsilon
\]  

VI. CARRY OUT SSFR TEST AND PARAMETER EXTRACTION

SSFR tests were performed on Montazaer-Ghaem rated 147.8 MVA gas Generator. The nominal values of the generator are shown in Table (3). Leakage reactance is extracted from design data and equals to 0.095 p.u. Armature and field resistances are taken as \( R = 0.00141 \Omega \) \( R_f = 0.1015 \Omega \) from generator technical document. Temperature during tests was measured as 27 °C, while operating temperature is supposed to be 100 °C.

The rotor position was changed by means of hydraulic pump which illustrated in Fig. 7. During positioning of the rotor, zero voltage on the field winding could not be precisely achieved, so the final position was determined by achieving the minimum induced field voltage. During measurements, signals became noisier as the frequency was decreased below 0. 1 Hz.

### Table (3) Nominal Values for MantazerGhaem gas unit synchronous generator

<table>
<thead>
<tr>
<th>Rated Power (MVA)</th>
<th>Rated Voltage (kV)</th>
<th>Rated current (A)</th>
<th>Speed (RPM)</th>
<th>Rated Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>147.775</td>
<td>13.8</td>
<td>6182</td>
<td>3000</td>
<td>50</td>
</tr>
</tbody>
</table>
During the test instantaneous value of measured current and voltage are recorded by transient recorder in each scanning frequency. Using Fourier transform, from the instantaneous measured values, RMS values are extracted by which operational impedances \( Z_d \), \( Z_q \) and \( G(s) \) (both magnitudes and angles) are calculated for the whole range of scanning frequency. The magnitudes and phase angles of \( Z_d \) and \( Z_q \) are illustrated in Fig.8, Fig.9 respectively.

<table>
<thead>
<tr>
<th>Table(4) calculated base parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armature Base Current</td>
</tr>
<tr>
<td>Armature Base Inductance</td>
</tr>
<tr>
<td>Field Base Current</td>
</tr>
<tr>
<td>Field Base Inductance</td>
</tr>
</tbody>
</table>

To obtain \( R_d, R_q \), armature impedances \((Z_d, Z_q)\) plot as a function of a frequency and extrapolate it to zero frequency to get the dc resistance as illustrated in Fig.11: \( R_d \), the dc resistance of one phase of armature winding in q-axis, should be normally the same as \( R_d \) which obtained during d-axis test, but due to the sensitivity of the result to this value we obtained these quantities separately. Using operational impedances \( Z_d, Z_q \) and \( R_d, R_q \), the d and q axes inductances are calculated as:

\[
L_d(s) = \frac{Z_d(s) - R_d}{s}, \quad L_q(s) = \frac{Z_q(s) - R_q}{s}
\]

which depicted in Fig (12-16). A fictitious quadrate rational function is used for finding \( L_d(0) \) and \( L_q(0) \) (Fig.12).

Field to armature turns ratio \( \frac{N_{fd}}{N_a} \) is calculated based on Fig. 10 as:

\[
\frac{N_{fd}}{N_a} = \lim_{s \to 0} \left[ \frac{1}{L_{ad}(0)} \frac{1}{s} \frac{\Delta e_{ad}(s)}{\Delta v_{ad}(s)} \right] = 12.18
\]

where \( L_{ad}(0) = L_d(0) - L_j \). The field resistance, referred to armature winding is:

\[
R_{fd} = \lim_{s \to 0} \left[ \frac{1}{s} \frac{\Delta e_{fd}(s)}{\Delta v_{fd}(s)} \right] = 0.0020 \ \Omega
\]

The extracted test results are summarized in table (5).

<table>
<thead>
<tr>
<th>Table(5) the extracted test result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armature Resistance in d-axes Test</td>
</tr>
<tr>
<td>Armature Resistance in q-axes Test</td>
</tr>
<tr>
<td>Field Resistance in Test</td>
</tr>
<tr>
<td>Ld(0)</td>
</tr>
<tr>
<td>Lq(0)</td>
</tr>
<tr>
<td>Nfd/Na</td>
</tr>
</tbody>
</table>

Fig.8) \( Z_d \) and \( Z_q \) magnitudes obtained by SSFR test

Fig.9) \( Z_d \) and \( Z_q \) phase angles obtained by SSFR test
Fig. 10) Transfer Impedance $Z_{dfo}$

Fig. 11) Extended window for low frequency magnitudes of $Z_d$ and $Z_q$ to obtain $R_d$ and $R_q$

Fig. 12) Finding $L_d(0)$ and $L_q(0)$ using a fictitious quadrature rational function

Fig. 13) $L_d$ magnitude fitting to obtain parameters, a second order model

Fig. 14) Angle of $L_d$ and fitted quad rational function, second order model

Fig. 15) $L_q$ magnitude fitting to obtain parameters, a second order model
For fitting $L_d$ and $L_q$ to obtain equivalent circuit parameters we used the Hook-Jeeves optimization technique [13]. All data processing was done in actual units and at the end p.u values was calculated relevantly. Curve fitting for finding $L_d$ and $L_q$ magnitude and phase using Hook-Jeeves method is illustrated in Fig.13 – Fig. 16.

Field resistance is modified according to operating temperature and actual value obtained from manufacturer. An unsaturated value for $L_{ad}$ in Henrys can be calculated from rated speed open circuit saturation curve:

$$L_{ad} = \left( \frac{3}{2} \frac{N_p}{N_f} \frac{V_r}{\omega f_m} \right)$$  \hspace{1cm} (14)

Where $V_f$ and $J_f$ define a point on the air gap lin, and $\omega$ is the rotor speed in electrical radians per second and $V_f$ is peak voltage line to neutral. Similarly in the quadrature- axis equivalent circuit $L_{aq}$ must be adjusted to its unsaturated value.

$L_{ad}$ and $L_{aq}$ are modified for operating flux density using linear equation of [2]. The final result for d and q axis is summarized in table (6) and table (7) respectively. The manufacturer parameter for d-axis and q-axis is shown in table (8).

VII. CONCLUSION

It has been demonstrated here that the problem of identification of the parameters of synchronous machines from the results of frequency response tests can be done by an essentially analytical process. The parameters are estimated using Hook-Jeeves pattern search method. Simulation and experimental results show that the parameters of model for a synchronous generator can be identified successfully and have good accuracy with parameters presented by manufacturer. The model can then be used for studying low frequency oscillations and design and tuning power system stabilizers.

VIII. ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of Iran Grid Management Company (IGMC) during the SSFR test carried out in this paper.

### Table 6: D-axes results

<table>
<thead>
<tr>
<th>Opt. Method</th>
<th>$R_d$ (pu)</th>
<th>$L_d$ (pu)</th>
<th>$R_l$ (pu)</th>
<th>$L_l$ (pu)</th>
<th>$L_{ad}(\text{Test})$ (pu)</th>
<th>$L_i$ (pu)</th>
<th>$R_a$ (pu)</th>
<th>$X_d'$ (pu)</th>
<th>$T_d'$ (s)</th>
<th>$X_d$ (pu)</th>
<th>$T_d$ (s)</th>
<th>$X_d$ (pu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook-Jeeves</td>
<td>0.001018</td>
<td>0.18182</td>
<td>0.96219</td>
<td>0.11716</td>
<td>2.22088</td>
<td>0.095</td>
<td>0.00109</td>
<td>0.16401</td>
<td>0.0190</td>
<td>0.2629</td>
<td>0.8526</td>
<td>2.288</td>
</tr>
<tr>
<td>LS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.00116</td>
<td>0.187</td>
<td>0.0158</td>
<td>0.237</td>
<td>0.794</td>
</tr>
</tbody>
</table>

### Table 7: Q-axes results

<table>
<thead>
<tr>
<th>Opt. Method</th>
<th>$R_q$ (pu)</th>
<th>$L_q$ (pu)</th>
<th>$R_l$ (pu)</th>
<th>$L_l$ (pu)</th>
<th>$L_{aq}(\text{Test})$ (pu)</th>
<th>$L_i$ (pu)</th>
<th>$R_a$ (pu)</th>
<th>$X_q'$ (pu)</th>
<th>$T_q'$ (s)</th>
<th>$X_q$ (pu)</th>
<th>$T_q$ (s)</th>
<th>$X_q$ (pu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hook-Jeeves</td>
<td>0.051411</td>
<td>0.098088</td>
<td>0.007403</td>
<td>0.379834</td>
<td>2.09899269/6</td>
<td>0.095</td>
<td>0.00109</td>
<td>0.17013</td>
<td>0.0206/12</td>
<td>0.4160</td>
<td>0.20/23</td>
<td>2.1676/4</td>
</tr>
<tr>
<td>LS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.0011/6</td>
<td>0.235</td>
<td>0.0595</td>
<td>1.79</td>
<td>0.20</td>
</tr>
</tbody>
</table>

**Fig.16)** Angle of $L_q$ and fitted quad rational function, second order model.
Table (8) Manufacturer provided data

<table>
<thead>
<tr>
<th>X'd (pu)</th>
<th>T'd (s)</th>
<th>X'd (pu)</th>
<th>Td (s)</th>
<th>X'q (pu)</th>
<th>T'q (s)</th>
<th>X'q (pu)</th>
<th>T'q (s)</th>
<th>X'q (pu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.19</td>
<td>0.021</td>
<td>0.28</td>
<td>0.88</td>
<td>2.29</td>
<td>0.19</td>
<td>0.021</td>
<td>0.39</td>
<td>0.15</td>
</tr>
</tbody>
</table>

REFERENCES


APPENDIX 1

Some relations between operational parameters and dynamical parameters are presented here.

\[
X'q = x_f + x_{ad} \quad \text{with}\quad x_f = x_{eq} + \frac{x_{eq}x_{ad}}{x_{ad} + x_f} \\
X'q = x_f + x_{eq} \quad \text{with}\quad x_f = x_{eq} + \frac{x_{eq}x_{ad}}{x_{ad} + x_f} \\
X'q = x_f + x_{ad} \quad \text{with}\quad x_f = x_{eq} + \frac{x_{eq}x_{ad}}{x_{ad} + x_f}
\]

APPENDIX 2

Technical specification of Power Amplifier which used For SSFR Tests:

**Embossed Output Current:** 0—10 Amp. Effective (+−10A DC)

**Voltage Range:** up to 230 volt Effective

**Band Width:** DC to 10 KHz - 3db Minimum Harmonic Content

Source and Sink Operation Possible Permissible Losses at 23 OC , 5kw up to temperature Trip, 2.5 KW Continuously Input/Output Galvanically Isolated Modulation by BNC Analog Input Supply Voltage 3*400 Volt Effective

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