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Behavioural Modelling of a Switched Reluctance Generator for Aircraft Power Systems

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Abstract—A system-level modelling technique for a switched reluctance generator (SRG) is described for aerospace applications. Unlike existing techniques, this model is very simple and only reproduces the average behaviour of the input-output variables that are required for system-level analysis of the aircraft power distribution system. The model is parameterised from the measured generator response, avoiding the need for a detailed knowledge of the equipment structure, which may be unavailable. The modelling procedure is described in detail and validated by measurements on a switched reluctance generator within an aircraft test facility.

Index Terms—Switched Reluctance Generator, Aerospace, Modelling, System Identification

I. INTRODUCTION

The more-electric-aircraft (MEA) concept is leading to an increase in on board electrical equipment to drive aircraft subsystems that have conventionally been supplied by pneumatic, hydraulic or mechanical means. The transition to MEA technologies is resulting in higher levels of on board electrical power, and more complex electrical subsystems [1]-[7]. Consequently there is a high risk of dynamic interactions and instability between the regulated power converters and motor drives within the system. Techniques are therefore required to allow these effects to be examined at the design stage, and to ensure good stability margins.

System-level dynamic models and simulations provide the basis to assure proper performance of a power distribution architecture [8]-[17]. Consequently, system-level behavioural models of power converters [18]-[26] have been recently developed as an alternative to conventional average-value or switched models. These models only compute the variables required for system level analysis (typically input-output signals), and can be parameterised from the measured converter response. Moreover, these models do not represent in detail the internal structure of the actual converter.

The switched reluctance machine (SRM) is one of the candidate technologies for future engine-embedded starter/generators due to its simple structure, robustness, and fault tolerance [27]-[31]. Existing modelling approaches for switched reluctance generators (SRGs) focus on a detailed description of the electromagnetic behaviour of the machine and switching behaviour of the converter [32]-[35]. As a result these models require a detailed knowledge of the internal structure of the machine and drive system. However, modern aerospace systems comprise many subsystems from a number of different manufacturers and the system designer may not have access to all internal details of each piece of equipment, which are required to build up a conventional SRG model. Also, excessively detailed models may lead to unacceptable simulation times when integrated together. Therefore these models are not well suited to system-level analysis.

To address these issues, a behavioural modelling technique for a SRG is proposed. The presented model is intended to be used for dynamic analysis of power distribution architectures at system-level, including stability, interactions with other subsystems, response during transients, etc [8]-[17]. The main features are:

- Simple representation of relationships between average terminal waveforms, leading to manageable system simulation times.
- Parameterization of dynamic components based on straightforward transient response measurements.
- The internal structure of the SRG is not represented in detail, thereby protecting confidential data.
- If required, the model can be provided with special features of the actual voltage controller, such as clamping or anti-windup functions.
This paper is organised as follows:

- The system under study is described in Section II.
- The proposed model is presented in Section III.
- The parameterisation method is explained and applied to the experimental system under study in Section IV.
- The model is validated and demonstrated for system-level analysis in section V.

II. SYSTEM DESCRIPTION

The sub-system under consideration in this work is shown in Fig 1 and comprises a commercial SRG which is driven by an engine emulator and loaded by a combination of resistive and active loads. The 30 kW SRG consists of a three-phase machine with twelve stator poles and eight rotor poles, and a conventional three-phase half-bridge converter. The SRG regulates the DC-bus at 540 V and supplies a maximum of 30 kW over a speed range of 7,000 rpm to 15,000 rpm.

The gas engine emulator is a 115 kW, 15,000 rpm, bidirectional induction machine drive and is commanded by the flight control system (FCS) which contains a generic two-spool gas engine model. The model takes environmental data, throttle position and electrical power off-take as inputs and outputs a speed command to the motor drive.

The active load can operate in constant current or constant power modes with a transient rise time of 10 ms. A detailed description of the aerospace system is given in [27].

III. MODELLING APPROACH

From a high level point of view the control stage may be considered to set the DC current, $i_m$, supplied by the SRG to the DC link capacitor and DC-bus to minimise the error between $v_{ref}$ and $v_{bus}$. Therefore the power stage is modelled as a controlled current source feeding the DC-bus and capacitor $C_{bus}$, leading to the ‘grey-box’ behavioural model shown in Fig. 3, which partially represents the inner structure of the SRG.

The relationship between the error signal and the averaged SRM current, $i_m$, is represented by $T_v$, which contains the elements of the actual controller, namely:

- Voltage regulator $VR$, comprising a linear proportional-integral term $R_v$, and any special functions such as clamping or anti-windup, denoted as “CF”.
- $H_v$, which represents the dynamic relationship between the voltage regulator command, $v_{com}$, and the averaged machine current $i_m$, including the block ‘Driver’ and power stage.
- ‘Delay $\tau$’ accounts for any transport delay.

Mechanical speed transients are assumed to be relatively slow compared to the electrical transients so that they are not dynamically reflected in $v_{bus}$. 
The averaged dynamic relationship between \(v_{\text{com}}\) and \(i_{\text{in}}\), modelled by \(H_r\), may be in general dependent on operating point, due to the nonlinear characteristics of the SR machine. However, it was found that \(H_r\) exhibits only a slight nonlinearity over the range of generator speed and power (shown in Section IV.E). Therefore \(H_r\) was assumed linear, providing a good compromise between model simplicity and performance. Nevertheless, dependence on operating point could be incorporated in the model by using a weighted combination of local linear models [22], [38].

Also, the ‘grey-box’ model structure allows returning of the voltage control or alternative control topologies to be easily implemented by modifying VR in Fig. 3.

### IV. MODEL PARAMETERISATION

By applying a small-signal perturbation to \(i_{\text{in}}\) in the model, Fig. 3, while \(v_{\text{ref}}\) is kept constant, the following expression for the output impedance is obtained:

\[
\frac{v_{\text{bus}}(s)}{i_{\text{in}}(s)}|_{v_{\text{ref}}(s)=0} = Z_o(s) = \frac{1}{sC_{\text{bus}}(s)} + T_v(s)
\]

where \(T_v(s)\) is a linear representation of the block \(T_v\) in the Laplace domain (the CF block is disabled) and is given by (2). \(e^{-\tau s}\) corresponds to the loop delay.

\[
T_v(s) = R_v(s)H_v(s)e^{-\tau s}
\]

As can be seen, \(Z_o(s)\) corresponds to the parallel connection of the impedance of \(C_{\text{bus}},\) \(Z_{\text{bus}}(s),\) with \(T_v(s)^{-1}.\) \(Z_o(s)\) can therefore be used to obtain several parameters for the SRG model. The transfer function \(Z_o(s)\) is identified in Section IV A. After that, \(C_{\text{bus}}, T_v(s)\) and CF are characterized (Sections IV B, C and D, respectively).

#### A. Output impedance identification \(Z_o(s)\)

A transfer function model can be identified for \(Z_o(s)\) from a set of input-output transient response measurements using parametric identification algorithms. These algorithms have been widely discussed in the literature [38], [39] and can be easily applied by using commercial tools, e.g. Matlab System Identification Toolbox [40]. A flowchart of the parametric identification procedure is depicted in Fig. 4 and described below.

1) **Transient response measurements**

A load step test is used to identify the output impedance, since it is easy to apply and leads to good identification results. The experimental setup comprises two resistors, \(R_1\) and \(R_2,\) a switch and a data acquisition system, Fig. 5.

The step change should be small so that the system response can be assumed linear (the clamping and anti-windup functions, CF in Fig. 3, are not activated).

2) **Model structure selection**

The general transfer function model structure, identified through parametric methods, is:

\[
y(k) = G(q)\cdot u(k) + H(q)\cdot e(k)
\]

where \(e(k)\) is white noise, \(u(k)\) is the system input and \(y(k)\) is the system output. \(G(q)\) and \(H(q)\) are the so-called input transfer function and error transfer function, respectively, and \(q\) is a shift operator \(q^i x(k) = x(k-i)).\) In this case \(u(k) = i_{\text{bus}}(k),\) \(y(k) = v_{\text{bus}}(k)\) and \(G(q) = Z_o(q).\)

Depending on the characteristics of \(G(q)\) and \(H(q),\) several transfer function models are defined [38], [39]. In this work the Output Error (OE) model \((H(q) = 1)\) is proposed, since a good trade-off between performance and complexity is achieved. This model structure has also been identified from step tests for system-level modelling of other converters in [23], [25], [26].

3) **Signal pre-processing**

Before identifying the model, the measured signals have to be pre-processed. First, their steady-state value has to be subtracted, since the transfer function model only accounts for the SRSG dynamics. Second, pre-filtering may be performed to minimise signal components which are not modelled by the transfer function (e.g. switching ripple). Both the input and the output signals have to be filtered using the same filter, otherwise the filter would be included in the identified model [38], [39].

4) **Model order selection**

Next, the model order of \(G(q)\) has to be selected. Several choices should be iteratively tested until acceptable identification results are obtained. A good attempt can be done by looking at the waveform shape of the measured step response [24].

5) **Optimisation algorithm**

Following this, the optimisation algorithm is applied to obtain the coefficients of the transfer function model. An OE model can be identified using the "oe" function of Matlab, which searches for the coefficients of \(G(q)\) by minimising the cost function COF given by (4). \(N\) is the number of samples.
**Validation of transfer function**

The transfer function obtained from the optimisation algorithm is evaluated by comparing the model response with the measured response (after signal pre-processing). This can be done using the Matlab function “compare”, which quantifies the fit as:

\[
\text{fit\%} = 100 \cdot \frac{\sqrt{\frac{1}{N} \sum_{k=1}^{N} \left( y(k) - \hat{y}(k) \right)^2}}{\sqrt{\frac{1}{N} \sum_{k=1}^{N} y(k)}},
\]

where \( \hat{y}(k) \) is the model output, \( y(k) = G(q) \cdot u(q) \). If a poor fit is obtained then the model order should be adjusted.

Finally, the resulting discrete model can be converted to a continuous model by using a discrete to continuous time domain transformation, e.g. zero order hold or Tustin. More details about this procedure (Fig. 4) can be found in [25].

**Experimental Identification**

The procedure shown in Fig. 4 has been applied to the SRG. Fig. 6 illustrates the response of the SRG to a 5 kW resistive load step (no clamping functions are activated under this test, so linear behaviour is ensured).

Good identification results have been achieved with a third order model. Fig. 7 shows the identified transfer function response overlaid with the measured response (after signal pre-processing) and demonstrates a good correlation, a fit of 88.37%.

The identified transfer function after transformation into the continuous domain is given by (6) and its frequency response is plotted in Fig. 8, where one can notice a low frequency pole at \( \approx 1.6 \text{ Hz} \) plus two complex conjugate poles at \( \approx 14 \text{ Hz} \).

\[
Z_o(s) = \frac{0.028s^3 + 140.6s^2 + 1.064 \cdot 10^4s + 4782}{s^3 + 44.6s^2 + 8587s + 8.21 \cdot 10^4}
\]  
(6)

B. **Bus capacitor \( C_{bus} \)**

According to (1), at high frequencies \( Z(s) \sim Z_{C_{bus}}(s) \) so, by analyzing \( Z(j\omega) \) at high frequencies (where \( Z(j\omega) \) exhibits capacitive behaviour) \( Z_{C_{bus}}(s) \) can be identified. In this case, \( Z(j\omega) \) exhibit capacitive behaviour above 50 Hz, and \( Z_{C_{bus}}(s) \) can be approximated by a capacitance of 7.2 mF from Fig. 8.

Concerning the equivalent series resistance (ESR), 28 m\( \Omega \) was estimated. Nevertheless, an accurate estimation of the ESR of 540 V capacitors from the step response is difficult, as its value is relatively small. Alternatively, the bus capacitor could be estimated from direct measurements at the output port using an impedance meter or impedance analyzer, as long as it is externally accessible.

C. **Regulation and machine dynamics \( T_v \)**

Once \( Z_{bus}(s) \) has been identified, \( T_v(s) \) can be obtained as

\[
T_v(s) = Z_v(s) - Z_{C_{bus}}(s) = \frac{1}{s} \frac{\partial}{\partial s} \left( Z_v(s) \right) \bigg|_{s=0}
\]

However, using (7) yields an unstable transfer function if a non-minimum phase transfer function is identified for \( Z_v(s) \). Such a problem can be overcome by considering that according to Fig. 3, under linear operation \( T_v(s) \) is dynamically related to the average machine current \( i_m(s) \) as

\[
T_v(s) = -i_m(s) \bigg|_{v_{bus}(s)} \bigg|_{s=0}
\]  
(8)
Thus, if \( i_m \) is estimated from the measurements as:

\[
i_m(k) = ZC_{bus}(q)^{-1} \cdot v_{bus}(k) + i_{bus}'(k) \tag{9}
\]

\( T_i(s) \) can be identified from \( i_m \) and \( v_{bus} \) by applying parametric identification.

The estimated machine current, \( i_m \), calculated from (9) and the waveforms depicted in Fig. 6 (\( v_{bus} \) and \( i_m \)), is shown in Fig. 9. It exhibits a large amount of high frequency ripple due to the large magnitude of \( ZC_{bus}(q)^{-1} \) at high frequency.

A transport delay of approximately 8 ms is apparent between the load switching and the beginning of the transient response. Hence, if \( i_m \)' and \( v_{bus} \), calculated from (9) and (10) corresponding to the product of \( R_i(s)H_i(s) \) to be identified from \( i_m' \) and \( v_{bus} \),

\[
R_i(s)H_i(s) = -\frac{i_{bus}'(s)}{v_{bus}(s)} \bigg|_{i_{bus}'(s) = 0} \tag{11}
\]

Therefore \( T_i(s) \) has been characterized as follows:

- \( i_m \) has been shifted 8 ms with respect to \( v_{bus} \) as given by (10). Then the delay in the model has been characterized as \( \tau = 8 \text{ms} \).
- A transfer function model, corresponding to \( R_i(s)H_i(s) \) has been identified from \( i_m' \) and \( v_{bus} \).

The identification of the transfer function model has been carried out by following the procedure shown in Fig. 4 but in this case \( y(k) = i_m'(k) \), \( u(k) = v_{bus}(k) \) and \( G(q) = R_i(q)H_i(q) \). Both \( i_m' \) and \( v_{bus} \) have been pre-filtered using a moving average filter of 25 samples (\( f_s = 5 \text{ kHz} \)) to attenuate the high frequency ripple.

The results are depicted in Fig. 11, where it is shown that the average behaviour of \( i_m' \) (after pre-filtering and offset subtraction) is accurately fitted by a third order transfer function.

The resulting transfer function after transformation into the continuous time domain is given by (12) and its frequency response is shown in Fig. 12, where some properties of the regulator, such as the low-frequency integrator, are apparent.

\[
R_i(s)H_i(s) = \frac{0.2933s^3 + 2987s^2 + 5.38 \times 10^7s + 4.622 \times 10^9}{s^3 + 9288s^2 + 5.81 \times 10^7s + 9.176 \times 10^9} \tag{12}
\]

Once \( R_i(s)H_i(s) \), \( C_{bus} \), and \( \tau \) have been characterized, the fitting performance of the overall generator model has been evaluated by comparing the frequency response of the identified output impedance \( Z(s) \) (6) with that of the resulting model (1). As shown in Fig. 13, the output impedance of the model is very close to that directly identified from the measured load step, so the model has been correctly parameterised.

Any prior knowledge about parameters such as the bus capacitor \( C_{bus} \) or the regulator tuning / architecture can be readily used to parameterise the model, simplifying the procedure.
D. Clamping functions CF

Sometimes the voltage regulator may contain special features, such as clamping or anti-windup functions, which are activated under certain situations and may influence the dynamic response of the SRG significantly. The proposed ‘grey-box’ model allows the implementation of this kind of function, denoted as CF in Fig. 3.

A formal methodology to incorporate clamping functions in the voltage controller is difficult to define. In this case a heuristic technique was employed based on fragmented intelligence from the designer and manufacturer together with experimental step response tests over the full operating range of the system. The relation between the clamping function parameters and experimental data is shown later in Fig. 16. A number of iterations were necessary to refine the modelling of the clamping functions and improve the fitting between the simulation and experimental results, ensuring an accurate controller representation over all operating conditions.

The clamping functions of the SRG under experimental study act as follows on the voltage compensator, which is a PI type.

- The output of the proportional term \( K_p \) is clamped to zero while \( v_{ref} - v_{bus} < 0 \) V.
- The output of the integral term \( K_i \) is reset if \( v_{ref} - v_{bus} < -18 \) V.
- The minimum value of the regulator output, \( v_{com} \), is limited to zero if the commanded signal from the PI is lower than zero.

These clamping functions are activated during a step down in load to limit the maximum output voltage of the generator.

Fig. 14 illustrates the behaviour of the clamping functions under a load step from 20 kW to 15 kW at \( n_m = 7,000 \) rpm. When the load is reduced, \( v_{bus} \) increases because the difference between \( i_m \) and \( i_o \) charges \( C_{bus} \). Consequently, the proportional term is disabled. Once \( v_{ref} - v_{bus} < -18 \) V, the integral term is reset, \( v_{com} = 0 \) and then \( v_{bus} \) decreases suddenly. Finally, when \( v_{ref} - v_{bus} \geq 0 \) V the regulator is re-enabled to control \( v_{bus} \).

To implement the clamping features of the voltage regulator, VR, the identified transfer function \( R_v(s)H_v(s) \) has been split in two. By expressing (12) in a zero-pole-gain representation, the following expression is obtained:

\[
R_v(s)H_v(s) = \frac{0.293 \times (s + 9.04) (s + 174.2) (s + 10000)}{(s + 0.158) (s + 62.8) (s + 9226)}
\]

where the dominant, lowest frequency pole-zero pair corresponds to the PI compensator \( R_v(s) \). By moving the lowest frequency pole to \( s \to 0 \) and neglecting the high frequency pole-zero pair, expressions for \( R_v(s) \) and \( H_v(s) \) are obtained as:

\[
R_v(s) = \frac{s + 9.04}{s}, \quad H_v(s) = 0.31 \times \frac{s + 174.2}{s + 62.82}
\]

From \( R_v(s) \) the proportional and integral terms of the PI regulator are obtained: \( K_p = 1 \) and \( K_i = 9.04 \).

Moreover, when \( v_{com} = 0 \), it has been found that the SRM is rapidly de-energized so that \( i_m \) suddenly decreases to zero with a slew rate of 4.2 A/ms (Fig. 14). This nonlinear effect cannot be accounted for by the transfer function model \( H_v(s) \). In order to reproduce such an effect, \( H_v(s) \) has been represented in a state-space form with a resettable integrator followed by a slew-rate limiter. This integrator is reset when \( v_{com} = 0 \) and then the machine de-energizing is properly reproduced.

The resulting implementation of the VR block presented in Fig. 3, including the clamping functions \( CF \), is shown in Fig. 15, where \( Th_1 = 0 \) and \( Th_2 = -18 \).
The modifications to the controller, Fig. 15, are:

- The SRG) up to full current if minor modifications are made to capable of regeneration (power flowing from the DC bus into actual controller can easily be included in the model.

- As clamping functions, anti-windup or other features of the behavioural model to be demonstrated, as special features such but allows the flexibility of the proposed ‘grey-box’ identified from this data through the following steps:

  - At time \( t_0 \) the load step occurs. The current \( i_m \) responds approximately 26 ms after \( t_0 \), which is significantly slower than the 8 ms transport delay identified in Fig. 10 for a step up in load. This indicates that \( K_p \) has been disabled as soon as \( v_{ref} \) - \( v_{bus} < 0 \), making the controller significantly slower. Therefore, the threshold \( Th_1 \) in Fig. 15 is estimated at zero.

- At time \( t_1 \), the machine current rapidly decreases, indicating that \( K_i \) has been disabled, so that \( v_{com} = 0 \). If the transport delay \( r \) (8 ms from Fig. 10) is subtracted from \( t_1 \) then the threshold \( Th_2 \) can be estimated from the voltage difference in Fig. 16 as -18V.

- The \( v_{com} \) saturation limit of zero can also be deduced from Fig. 16, as \( i_m \) is always a positive value.

The clamping functions are specific to the SRG under test, but allows the flexibility of the proposed ‘grey-box’ behavioural model to be demonstrated, as special features such as clamping functions, anti-windup or other features of the actual controller can easily be included in the model.

The SRG behavioural model presented in Section IV is capable of regeneration (power flowing from the DC bus into the SRG) up to full current if minor modifications are made to the controller. The modifications to the controller, Fig. 15, are:

1. The \( K_p \) component is enabled for negative deviations in DC bus voltage (the reset on the \( K_p \) term is disabled). Without this \( v_{com} \) and the DC current of the SRM would be zero and there would be no power flow.

2. The zero limit on the \( v_{com} \) signal is disabled to allow \( v_{com} \) to be negative for regeneration

   An additional modification to the controller is required to prevent overvoltage conditions; the reset on the \( K_i \) component is disabled, otherwise this would limit the functionality of the integral component and cause poor regulation of the DC voltage.

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**Fig. 16** Expanded view of Fig. 14 to demonstrate the process for estimating the parameters of the clamping function

**Fig. 17** Analysis of output impedance dependence on operating point: given by power level and speed.

### E. Justification for linearity assumption

Fig. 17 shows the frequency response of the output impedance identified by applying 5 kW steps for different load and speed conditions (the clamping function is disabled). The power listed in the figure is the intermediate power level.

In Fig. 17 the generator exhibits a resonant frequency at approximately 14 Hz for all operating conditions shown with all responses being very similar above the resonant frequency, as the response in dominated by \( C_{bus} \). Below the resonant frequency there is a slight dependence on operating condition. This dependence has been neglected to simplify the model and so \( H_s \) is represented as a LTI system.

### V. Model validation

The ‘grey-box’ model of the SRG has been implemented in the circuit simulator PSIM for validation purposes. A set of load step tests have been carried out both experimentally and by simulation, and the results from both tests have been compared. Both a passive and a constant power load have been used.

1) Passive load steps

Several resistive load steps with different magnitudes have been performed at different speeds in order to validate the model behaviour over the full operating range, as shown in Fig. 18.

Fig. 19 shows a comparison between the measured response and the simulated response for two 5 kW load steps. The first test, shown in Fig. 19.a, corresponds to that used for model identification (15 kW to 20 kW at \( n_m = 7,000 \) rpm). As may be expected, the model response is very close to the measured response.

The second test, shown in Fig. 19.b, is a step from 25 kW to full load (30 kW) at \( n_m = 11,000 \) rpm. Small differences between the model response and the measured response are observed. Those differences are due to slight nonlinearities of the SRM not reproduced by the model, since the block \( H_s \) has been approximated by a LTI model.
Fig. 18 Validation of the model under generating operation with a passive stepped load a) Experimental setup b) Simulated schematic.

Fig. 19 Measured response (black traces) vs simulated response (grey traces) under resistive load steps a) from 15 kW to 20 kW at \( n_m = 7,000 \text{ rpm} \) b) from 25 kW to 30 kW at \( n_m = 11,000 \text{ rpm} \).

Fig. 20 shows validation results for a step increase and decrease in load from 10 kW to 20 kW and back at maximum speed, 15,000 rpm. The non-symmetrical behavior of the SRG is evident and is due to the activation of the clamping functions during the step decrease in load. As can be seen, the model reproduces properly the response of the SRG both under increases and decreases in load. This validates the clamping functions implemented in the model.

Fig. 20 Measured response (black traces) vs simulated response (grey traces). Resistive load step up from 10 kW to 20 kW followed by a step down to 10 kW at \( n_m = 15,000 \text{ rpm} \).

Fig. 21 Measured response (black traces) vs simulated response (grey traces). Resistive load step up from 10 kW to 20 kW followed by a step down to 10 kW at \( n_m = 15,000 \text{ rpm} \) without the clamping functions \( CF \) in the simulation model.

To illustrate the importance of the clamping functions, the simulation result in Fig. 20 has been repeated with the \( CF \) block disabled. The results (Fig. 21) are unchanged in response to the load increase but there are significant discrepancies when the load is reduced, particularly in terms of the peak deviation of the voltage.

2) Constant power load steps

With the active load configured in constant power mode, the generator system was subjected to load step changes as in Fig. 22.a. The load is commanded by a high bandwidth control loop (around 3 kHz) so, for the purpose of simulation, it was assumed to be infinite. Hence, the active load has been simulated in PSIM as shown in Fig. 22.b, where the input filter capacitor is 110 \( \mu \text{F} \).

The measured and simulated responses for step increases and decreases in power load are shown in Fig. 23.a and Fig. 23.b. The simulated response is close to the measured one in all cases. The observed differences are relatively small and, as
discussed earlier, they are due to slight nonlinearities of the SRM which are not accounted for by the model. Nevertheless, the key transient response characteristics such as the settling time and the overshoot are predicted by the model with a good degree of accuracy.

VI. CONCLUSIONS

A behavioural modelling technique for a switched reluctance generator is proposed. The model is simple, reproduces the average behaviour of the input-output signals of the generator and can be fully parameterised using a set of simple tests. The model is particularly suitable for system level studies such as examining power generation and distribution on board a more-electric aircraft.

A comprehensive illustration of the proposed methodology has been presented by making use of a switched reluctance generator located in an aerospace test facility. For validation purposes, the model has been implemented in a virtual test bench and its response has been compared to that of the real system under a variety of tests over the whole operating range of the generator, consisting of passive and active load steps. In all cases, the model has reproduced with good accuracy the actual system response. The capability of the model to include nonlinear functions of the regulator, such as clamping or anti-windup, has also been illustrated.

REFERENCES


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