**Parameter Estimation of Electric Machines – Review**

Prepared by Serhat OZKUCUK

**General Concept**

**Off-line Parameter Estimation**

Determining the parameter in stand-still or rotation at no-load.

**Self Commission** **Commission**

No previous knowledge Some previous knowledge

**On-line Parameter Estimation**

To adapt the motor parameter during the drive operation

**Spectral analysis Observer based Systems Model reference adaptive system Others**

Spectral analysis : measured response from *injection test signal* or *existing characteristic harmonic in*

*(stator) V/I spectrum*.

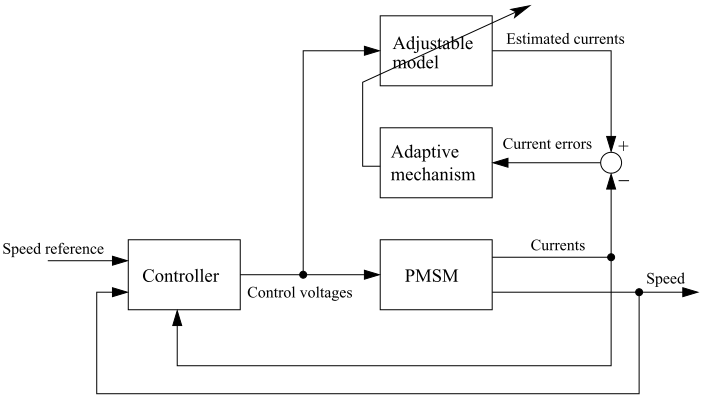
Observer based systems : Extended **Kalman Filter** (EKF) (Observer)

Reduced order Kalman Filter (reducing computation stress)

Recursive Least Square (RLS) algorithm (Special case of Kalman Filter)

Model Reference adaptive system (MRAS) : Calculated from model

Calculated from measured signals



Measure or use some known parameter

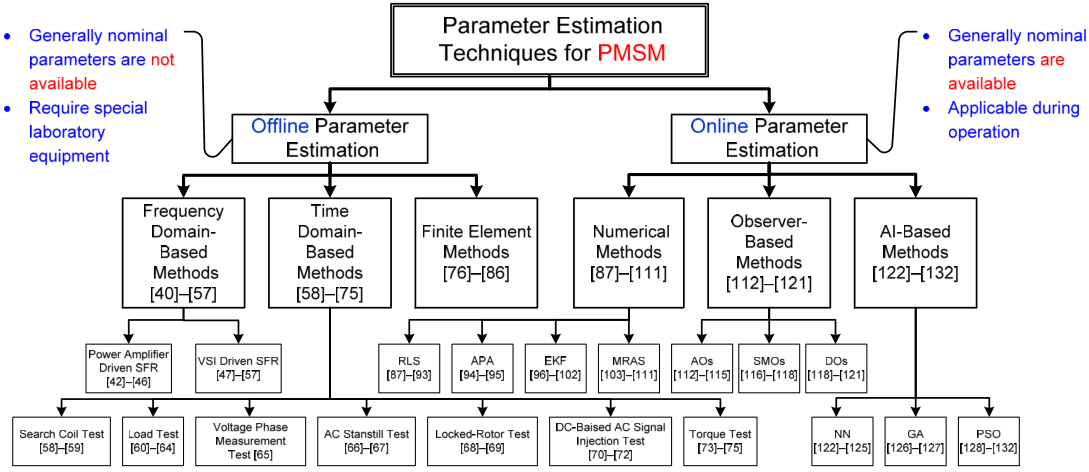
Define/determine parameter error

Drive adaptive mechanism

Correction

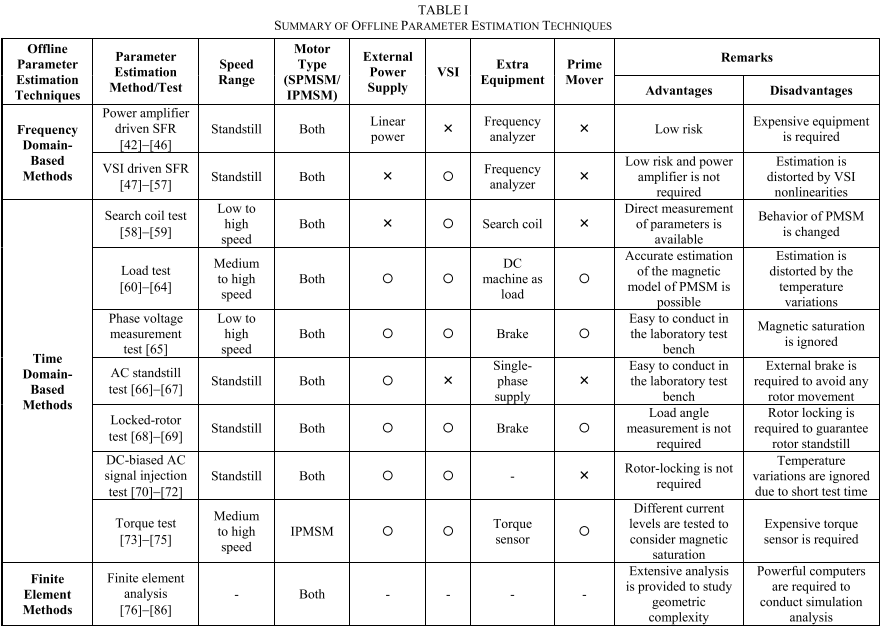
Others : AI, Neural Network, Particle Swarm, Fuzzy Logic

SUMMARY CHART



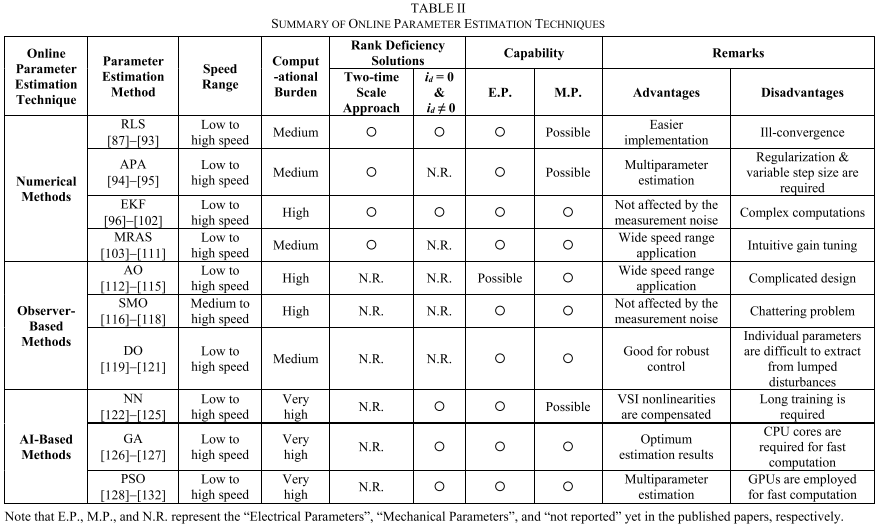
[A Comprehensive Review of State-of-the-Art Parameter Estimation Techniques for Permanent Magnet Synchronous Motors in Wide Speed Range, M.Rafaq, J.Jung]

OFFLINE PARAMETER ESTIMATIONs



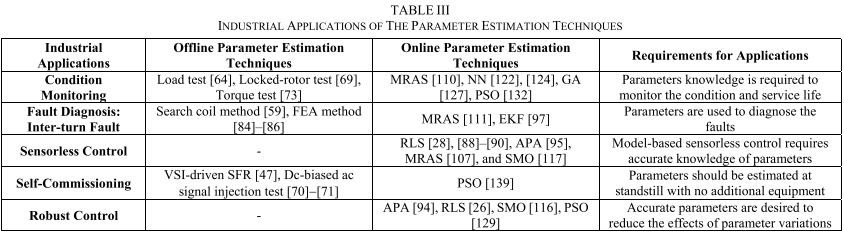
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ONLINE PARAMETER ESTIMATION



[A Comprehensive Review of State-of-the-Art Parameter Estimation Techniques for Permanent Magnet Synchronous Motors in Wide Speed Range, M.Rafaq, J.Jung]

INDUSTRIAL APPs.



[A Comprehensive Review of State-of-the-Art Parameter Estimation Techniques for Permanent Magnet Synchronous Motors in Wide Speed Range, M.Rafaq, J.Jung]

**Open Issues for Research**

1. VSI-driven frequency domain-based methods have implementation challenges due to VSI nonlinearities. These methods should be able to consider the effects of mutual inductances and magnetic saturations during the parameter estimation of the PMSMs.
2. Offline estimation techniques at standstill require more attention to design the industrial control applications and smoothly operate the PMSMs for a longer period of time. Moreover, they are of great interest for self- commissioning of the PMSMs.
3. Cost-effective and simple parameter estimation methods should be designed that do not require a special laboratory environment and can easily estimate the parameters without disconnecting the PMSM from its load.
4. Simultaneous estimation of the electrical and mechanical parameters of the PMSMs is one of the major concerns because of rank-deficient problems. More techniques should be developed to estimate all the parameters at the same time and avoid the problems of under-estimation and over-estimation of the parameters.
5. Standardization of parameter estimation methods for PMSMs is required to facilitate industrial implementation.
6. New methods for parameter estimation and applications should be worked in parallel which can solve all the problems with minimum tradeoffs.

**KEYHANI, CH22 - MODELING AND PARAMETER IDENTIFICATION OF ELECTRIC MACHINES**

In this report, modeling, parameter identification and estimation of electric machines (synchronous, induction, switched reluctance) are searched and core aspects and some special techniques are summarized.

**1. Introduction**

Modeling the dynamism of a system has a critical role for designing the control system. Modeling often results in a parametric model of the system which contains several unknown parameters. Experimental data are needed to estimate the unknown parameters. Generally, the parameter estimation from test data can be done in frequency-domain (noise-corrupted data are used for estimation) or time domain (maximum likelihood technique for remove the noise effect from estimated parameter in frequency domain).

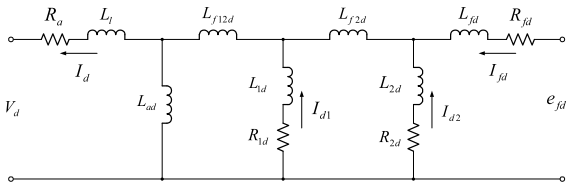
**2. The effect of noise on frequency domain parameter estimation of synchronous machine**

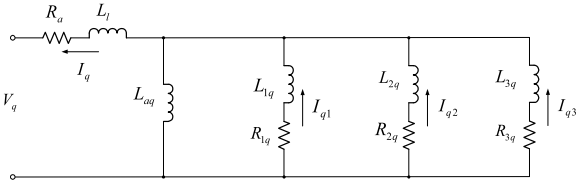
Modeling and estimation works done via 2nd (SSFR2) or 3rd (SSFR3) order model structure (they are not enough for exact mathematical representation) that assuming there are two or three rotor winding model is used in estimation of machine parameter from test data, but, there are an infinite number of rotor circuit. So, even if it is assumed that model is correct, estimated parameters will not unique that are obtained from measurement (noise corrupted frequency response data is obtained from complex actual high order rotor circuitry machine that has unknown structure and parameters). In this case, simulated model response and the measured response will be different due to noise. Therefore, the structural identification problem and the parameter estimation problem should be studied separately. There is a need to show that the measurements noise will not corrupt the estimated parameters when the parameters of an assumed structure are estimated from the frequency response measurements.

For this purpose,

Step 1: Stand-Still Freq. Resp. SSFR3 3rd order model with known parameters is simulated then, obtained data is being noise-corrupted by a known noise distribution.

Step 2: Estimate the parameters of this model from the noise-corrupted data and compare with the known parameter in Step 1.

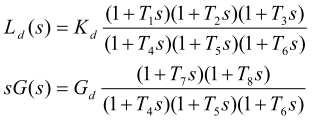
 (d-axis eq. circuit of SSFR3)

(q-axis eq. circuit of SSFR3)

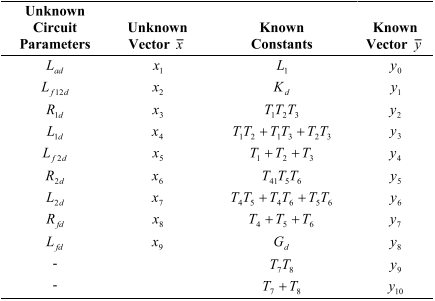
\*This model can be reduced 2nd or 1st order with throwing away parallel paths.

**2.1. Parameter Estimation Technique**

Transfer function of the d-axis SSFR3 eq. circuit:



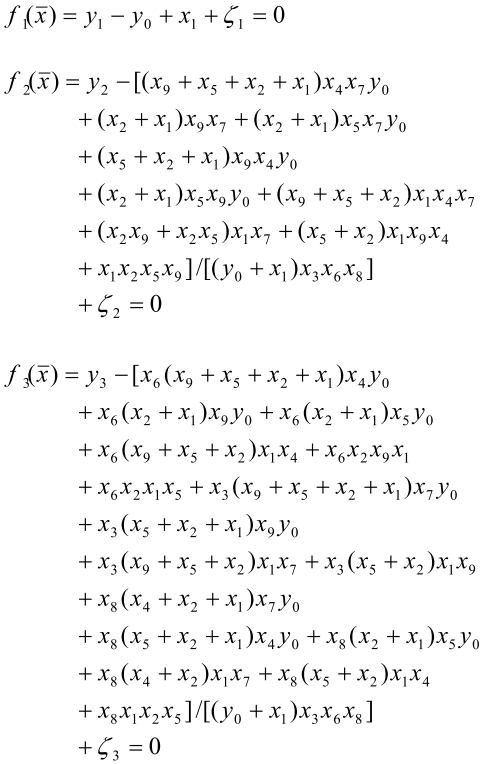
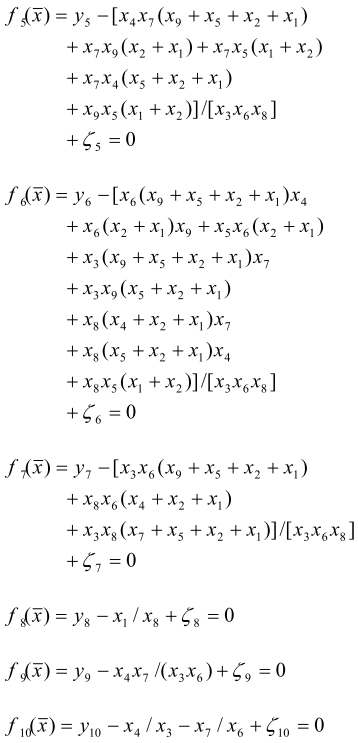
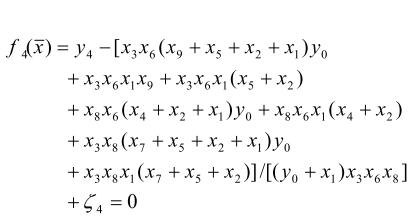
Definition of unknowns () and knowns ( : estimated from measured freq. resp. data of the transfer function) of d-axis circuit



estimated by curve fitting technique. The complex nonlinear eq. of is obtained by using MACSYMA, Mathematica, Symbolic Math Toolbox etc. (computer algebra system CAS)

 where, i = 1, … ,10 ,

ζ : noise associated with each element *yi*

Newton-Raphson method is used for solve these 10 nonlinear eqs. Iteratively. (10 eqs. 9 unknowns : there are multiple solutions depending on which eq is ignored). If the measured freq. resp. data are noise free, ζ i =0 for i=1, … ,10, 10 eqs. Gives unique solution regardless of the ignored eq.

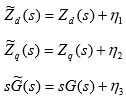
 until the residuals are smaller than a predetermined error ε ()

Before the iterative approximation can be carried out, a good initial estimate if the unknown vector is essential for convergence to a solution. In this report, the initialization of the unknown vector is performed by using the method developed by [**SD Umans, JA Mallick, GL Wilson, Modeling of solid rotor turbogenerators – Part I: Theory and techniques, IEEE Transactions on Power App. Systems, Vol. PAS-97, No. 1, 1978, Pages 269- 277**]. In his method, is discarded and the remaining nine equations are solved for the nine parameters.

**Study Process :**

Monticello generating unit SSFR3 [PL Dandeno, AT Poray, Development of detailed turbogenerator equivalent circuits from standstill frequency response measurements, IEEE Transactions on Power App. Systems, Vol. PAS-100, No. 4, April 1981, Pages 1646-1655] -> synthetic frequency response data -> corrupted with a uniformly dist. Noise (zero mean, varying degrees of signal to noise ratios)

Noise corrupted data: , (noise: ηi)

d-q axes transfer functions: nonlinear least square curve-fitting techniques [D Marquardt, An algorithm for least-square estimation if nonlinear parameters, Journal of Soc. Indust. And Appl. Math. II, 1963, Pages 431-441]

Both magnitude and phase angle data were used in estimating the time constants.

Monticello generator parameters, corresponding to the SSFR3 model structures, were then recalculated using the Newton-Raphson method discussed earlier.

The same model structure was retained so that any discrepancy observed in the recalculated values of the machines parameters, could be specifically ascribed to the noise introduced in the synthetic data.

**Results:**

Based on the results of this study, it is concluded that:

1) Noise, which is inherently present in the field test data, has significant impact on the synchronous machine parameters estimated from the SSFR test data using curve-fitting techniques.

2) Multiple solution sets for the machine parameters are obtained depending upon the equation ignored from the set of relevant equations. In some cases the solution may not even converge.

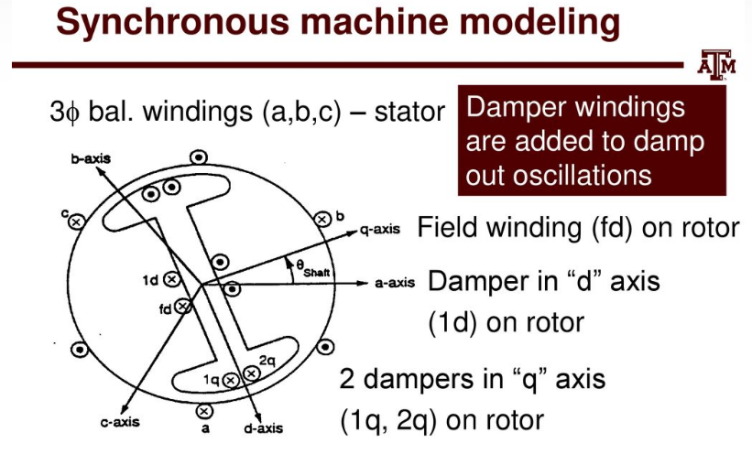
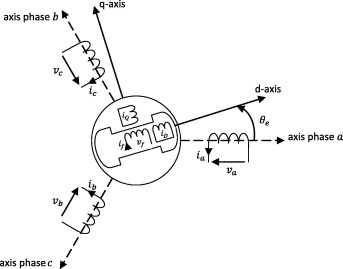
3) Estimated values of the machine parameters are very sensitive to the vales of armature resistance used in the data analysis. Even a 0.5% error in the value of armature resistance could result in unrealistic estimation of the machine parameters.

4) A technique should be developed which provides a unique physically realizable machine model even when the test data are noise-corrupted.

In this section, it was shown that multiple parameter sets will be obtained when the transfer functions of a solid-rotor synchronous machine are estimated from noise- corrupted, frequency-domain data and then, the machine parameters are computed from the estimated machine transfer function’s time constants.

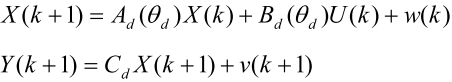
**3. Maximum Likelihood Estimation**

**Stand-Still Synchronous Machine Model for Time-Domain Parameter Estimation**

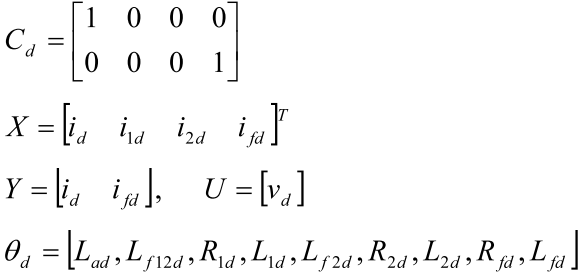
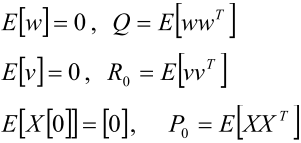
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Appendix çözümleri gelecek

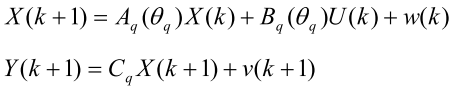
Model of D-Axis :

****🡪 rotor is two damper wdgs (SSFR3)

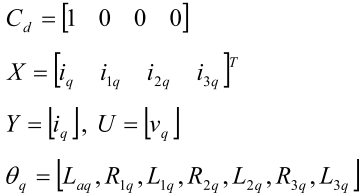
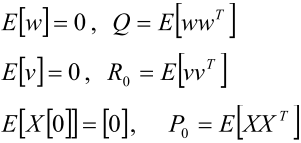
🡪stand-still discrete d-axis model

 Assumptions: 

Model of Q-Axis :

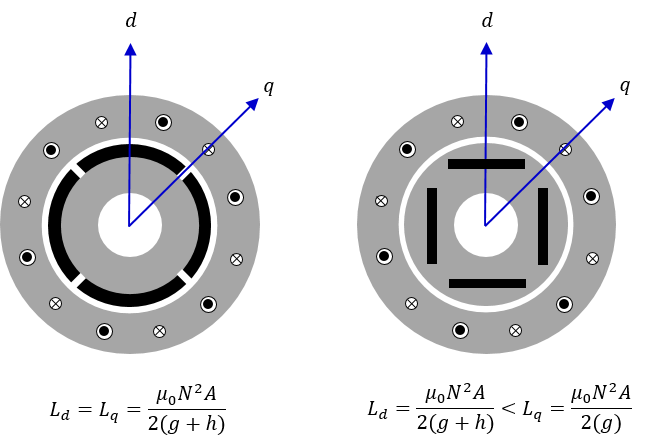
****🡪 rotor is two damper wdgs (SSFR3)

🡪stand-still discrete d-axis model

 Assumptions: 

**SOME CRITICAL DATA BRIEF:**

SPMSM vs IPMSM (g: gap length, h: PM width)



DYNAMIC MODEL OF IPMSM (SPMSM : )

Electrical Parameters

Mechanical Parameters

