Application of Kalman Filter in Power System Diagnostics

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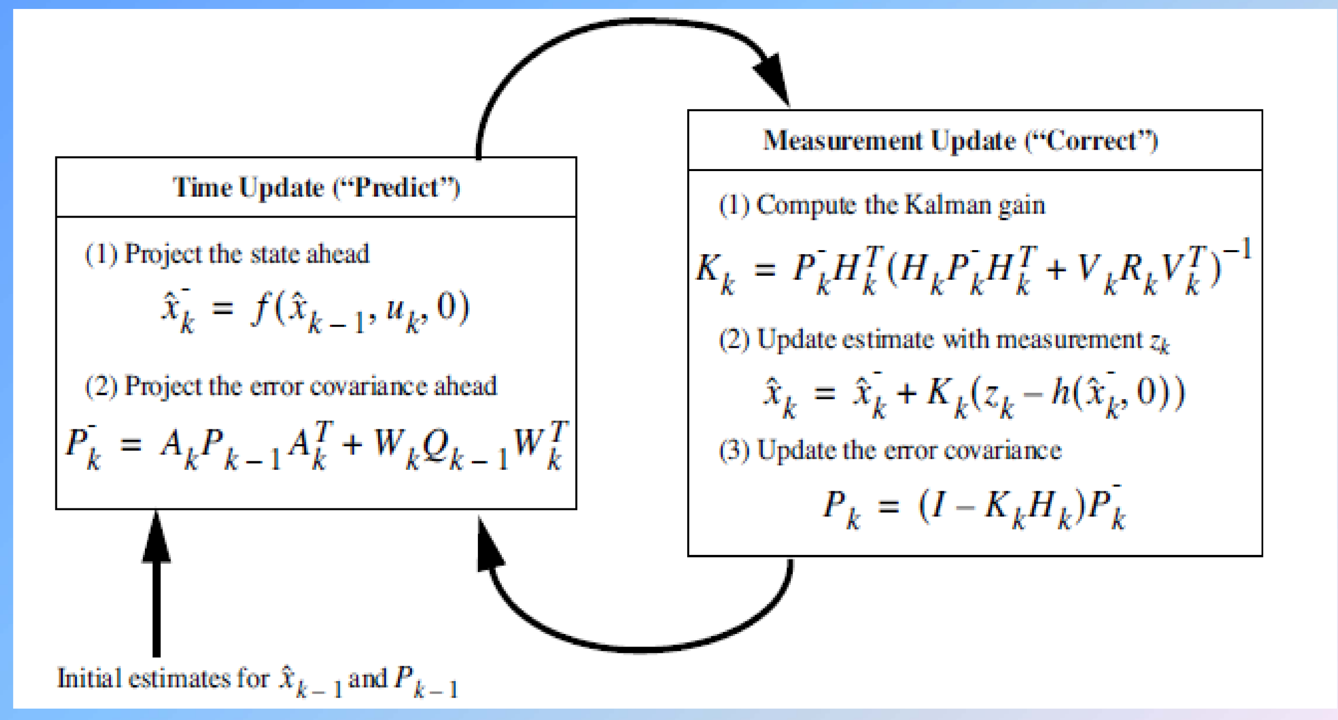
Research Objectives

- Improvement of power system on-line data processing and system diagnostics:
  - Disturbance event detection (faults) and classification
  - Harmonics Estimation
  - Disturbance source tracking: Harmonics source identification, fault location, and others.
- Optimal use of measurement devices, relays, PQ meters and IEDs in the power grid.
- Decrease cost associated with harmonic estimation and filtering.
- Decrease cost associated with protection system and maintenance through more robust identification and tracking methods.

Main Areas of Diagnostics

- Kalman filtering would be investigated for its potential detection, classification and tracking of the following:
  - Harmonics (Estimation and tracking)
  - Power System frequency estimation
  - Faults analysis(classification and location)
  - Voltage flicker.
  - Voltage dips
- The main emphasis of the research is given to harmonic estimation and tracking; fault classification and location.

The Discrete Kalman Filter Algorithm



The Discrete Kalman Filter for Harmonics Estimation

- Can track harmonics with time-varying magnitudes.
- Can estimate harmonics, inter-harmonics and sub-harmonics if frequencies are known.
- Can estimate the state from limited amount of data.
- Overcomes the limitations of the Fast Fourier Transform

Harmonic Estimation of Corrupted Signal Example

- A distorted signal can be represented as:

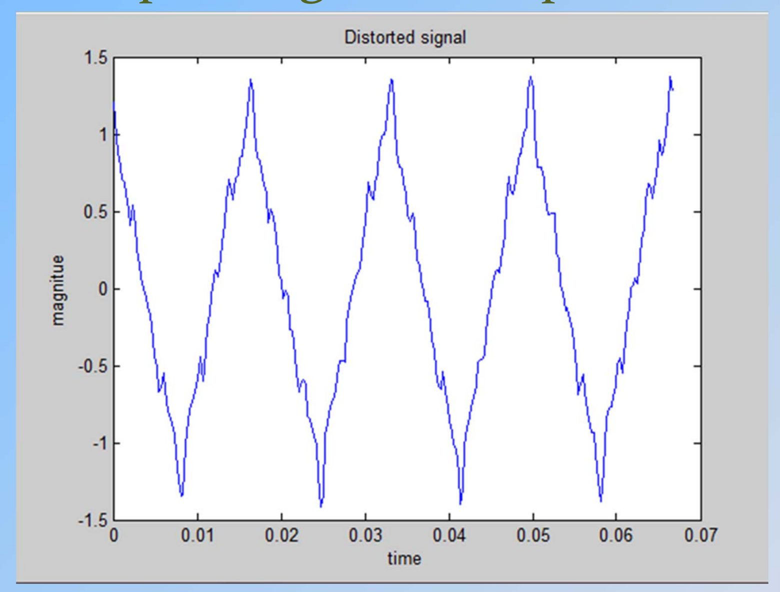
$$s(t) = \sum_{i=1}^{n} A_i(t)\cos(i\omega t + \theta_i)$$

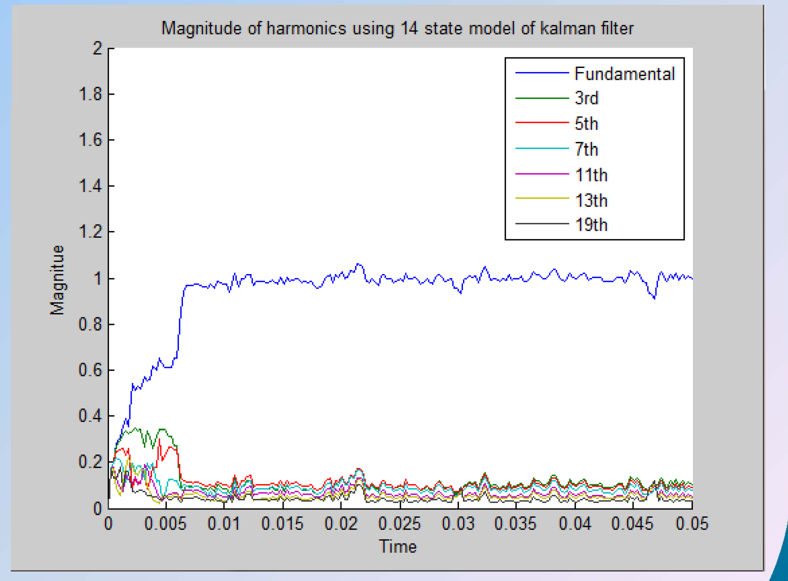
- The signal is decomposed into real and imaginary parts and the following state-space model is used [1]:

$$\begin{bmatrix} x1 \\ x2 \\ \dots \\ x2n-1 \\ x2n \end{bmatrix}_{k+1} = \begin{bmatrix} 1 & 0 & . & 0 & 0 \\ 0 & 1 & . & 0 & 0 \\ . & . & . & . & . \\ 0 & 0 & . & 1 & 0 \\ 0 & 0 & . & 0 & 1 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ \dots \\ x2n-1 \\ x2n \end{bmatrix}_{k} + \begin{bmatrix} \alpha 1 \\ \alpha 2 \\ \dots \\ \alpha 2n-1 \\ \alpha 2n \end{bmatrix}_{k} w_k$$

- Measurement Relationship [1]

$$z_k = H_k x_k + v_k = \begin{bmatrix} \cos(\omega k \Delta t) \\ -\sin(\omega k \Delta t) \\ \dots \\ \cos(n\omega k \Delta t) \\ -\sin(n\omega k \Delta t) \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ \dots \\ x2n-1 \\ x2n \end{bmatrix}_{k} + v$$

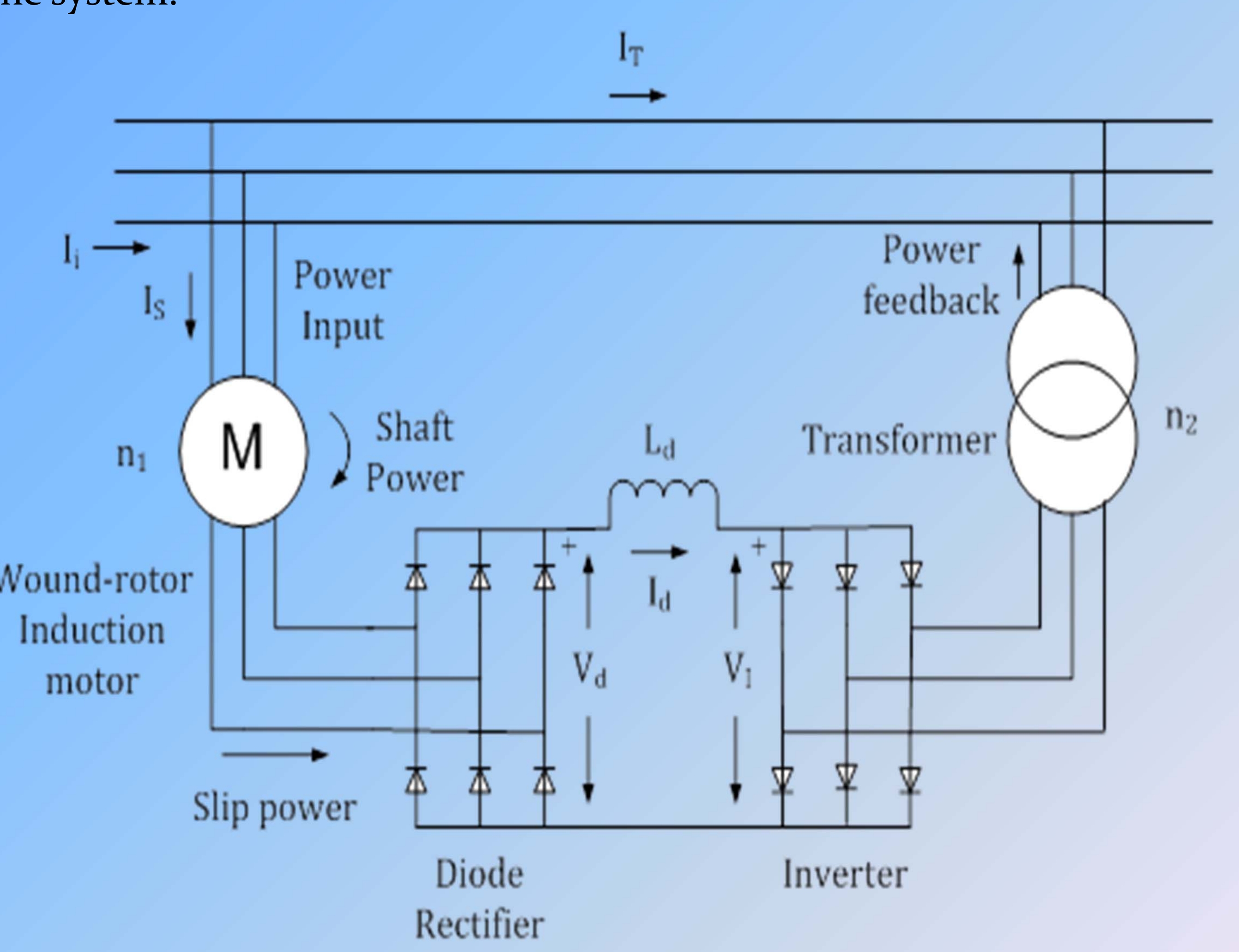




[1] W. C. E. B. M. Adly A. Girgis, "A Digital Recurisve Measurment Scheme for On-Line Tacking of Power System Haramonics.," *IEEE Transactions on Power Delivery*, vol. 6, no. 3, pp. 1153-1160, 1991

Future Experimental Setup

Static-Kramer Drive is a very suitable system for experimentation since harmonics, sub-harmonics and inter-harmonics are generated within this system and the Kalman filter applicability could be validated. Measurements would be taken at the terminals and Kalman filtering would be applied to estimate harmonics, inter-harmonics and sub-harmonics generated at different locations in the system.

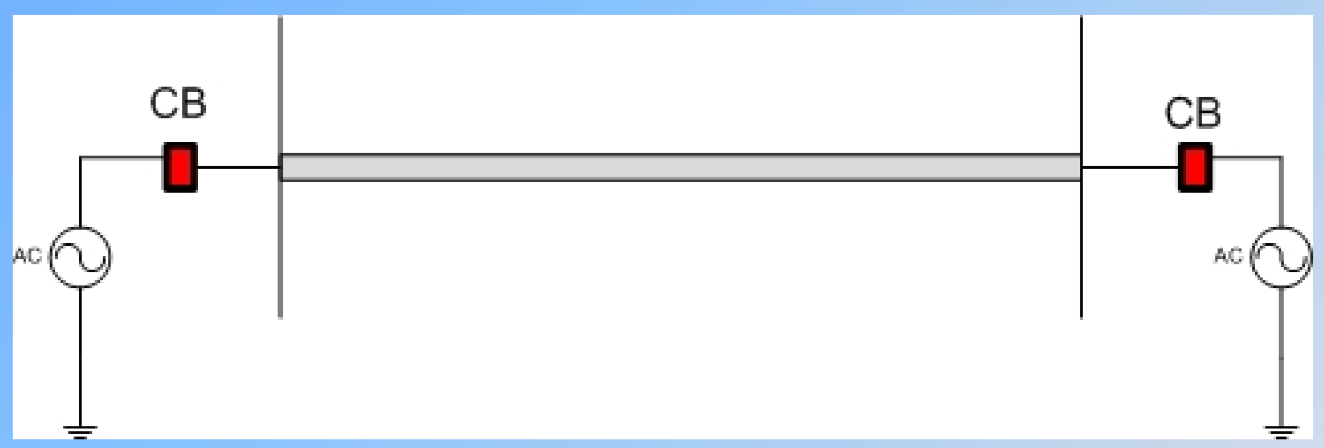


Static-Kramer Drive

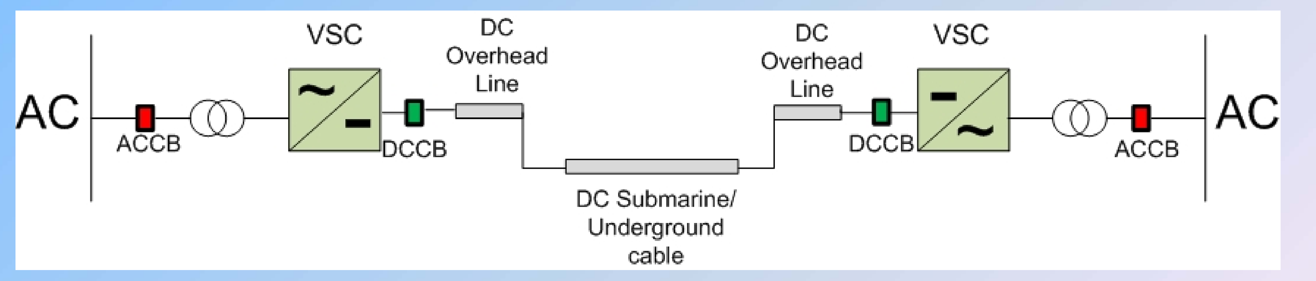
Further Research at High Voltage

Terminal measurements would be processed through Kalman filter for fault identification, classification and location in high voltage power system applications. Notable examples include:

- High Voltage AC Transmission Systems
- Voltage Sourced Converter Based HVDC Applications
- Conventional HVDC Applications



AC Transmission System



HVDC Transmission System