Fictive axis emulation (FAE) for single-phase inverter

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Table of Contents

Fictive axis emulation is a vector control technique that is mostly used in single-phase inverter applications, where the second axis β of a rotating reference frame needs to be emulated in order to support all vector computations.

Generally, the control of single-phase systems significantly differs from that of three-phase systems. Notably, numerous well-known concepts such as the separation of direct and quadrature axes – linked to active and reactive power flows – cannot be easily derived from coordinate transformations, simply because only one phase is available! This difference often justifies a preference for specific control techniques such as the use of Proportional Resonant (PR) controllers, rather than conventional vector control in a rotating (also called synchronous) reference frame.

That said, vector control techniques can also be used in single-phase applications, provided that a second axis β is emulated in order to support all vector computations (even though β-related references and quantities may be disregarded at the end of the control process). The benefit of such an approach is that, since coordinate transformations can be used, active and reactive power flows can be manipulated *as usual* (i.e. within a rotating reference frame).

Software resources

FAE_2015a.slxDownload
FAE_subsystem_2015a.slxDownload

Operating principles of FAE

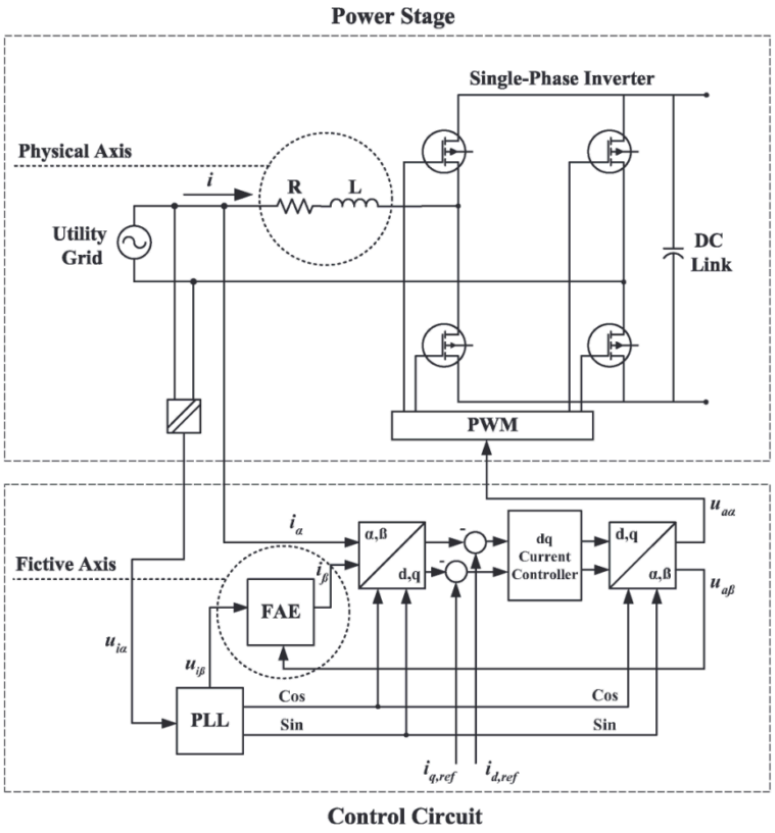
Emulating the beta component

The most obvious technique for emulating the β axis is to delay the available α axis by a quarter period. This results in a simple, yet robust implementation, but which unavoidably impacts the overall control chain due to the said delay. An alternative approach was first proposed by [1], essentially consisting of using an estimator for emulating the current that would flow on the β axis. In practice, this estimator can be easily derived from the plant model, which is needed anyway for the purposes of the control design.

This approach can be easily understood by observing the following figure, taken from [1], which highlights:

- The *Physical Axis* (α axis), which can be modeled as a first-order system where the current can be physically measured as $I_\alpha = \frac{1}{sL+R}(V_{g,\alpha} - E_{g,\alpha})$.
- The *Emulated Axis* (β axis), which can re-use the same model for estimating the current that would flow into the system, such as $I_\beta = \frac{1}{sL+R}(V_{g,\beta} - E_{g,\beta})$.

where Vg is the utility grid voltage and Eg is the converter voltage produced between the two phase-legs. In practice, $lV_{g,\alpha}$ and $lV_{g,\beta}$ are often directly made available by the PLL block, which is implemented using a Second-Order Generalized Integrator (SOGI).



Principle of fictive axis emulation on a single-phase inverter

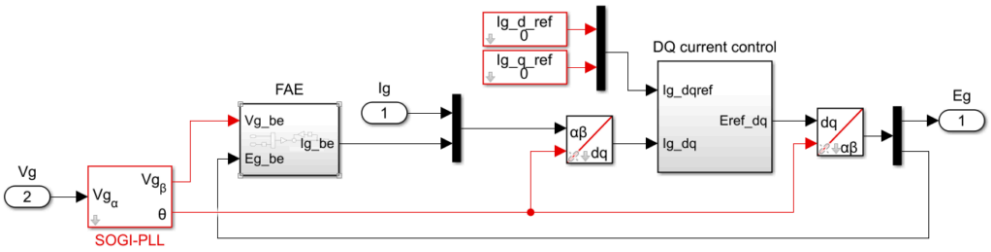
Academic references

[1] B. Bahrani, A. Rufer, S. Kenzelmann and L. Lopes, “Vector control of single-phase voltage-source converters based on fictive-axis emulation,” in IEEE Trans. Ind. Appl., Vol. 47, N° 2, Apr. 2011.

Implementation of fictive axis emulation

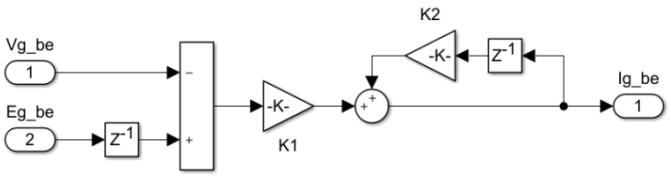
FAE for grid-tie inverter in Simulink

The provided Simulink file implements the inverter grid current control as shown below.



Fictive axis emulation for a grid-tie inverter in Simulink

The implementation of the FAE estimator itself is:



Simulink implementation of a FAE estimator

With

$$K_1 = \frac{T_s}{L_g + R_g T_s} \; and \; K_2 = \frac{L_g}{L_g + R_g T_s}$$

FAE in C/C++ code

The imperix IDE provides numerous pre-written and pre-optimized functions. Dedicated routines for fictive axis emulation exist as such within the `controllers.h/.cpp` files.

As for controllers, FAE-related routines are based on:

- A pseudo-object `FAEparameters`, which contains pre-computed parameters as well as state variables.
- A configuration function, meant to be called during `UserInit()`, named `ConfigFAE()`.
- A run-time function, meant to be called during the user-level ISR, such as `UserInterrupt()`, named `RunFAE()`.

The necessary parameters are documented within the `controller.h` header file. They are namely:

- `L` and `R`, the parameter values of the grid inductor (plant).
- `tsample`, the sampling (interrupt) period.

The source code of the related routines is given below.

```
void ConfigFAE(FAEParameters* me, float R, float L, float tsample){
  // Precompute the parameters offline:
  me->a = tsample/(L + R * tsample);
  me->b = L/(L + R * tsample);

  // Initialize the state quantities:
  me->state = 0.0;
}
```

```
float RunFAE(FAEParameters *me, float delta){
  // Apply the first-order transfer function:
  me->state = me->a * delta + me->b * me->state;

  return me->state;
}Code language: C++ (cpp)
```

The code below gives a use case example of both routines:

```
#include "../API/controllers.h"            // Discrete-time controllers
FAEParameters FAE;                         // Pseudo-object containing the FAE parameters

float R = 0.015;                           // Grid inductor ESR (Ohm)
float L = 0.0025;                          // Grid inductor value (H)

tUserSafe UserInit(void){
  ConfigFAE(&FAE, R, L, SAMPLING_PERIOD);
}

tUserSafe UserInterrupt(void){
  // ... some code
  Ig.imaginary = RunFAE(&FAE, Eg.imaginary - Ug.imaginary);
  // ... some code
}Code language: C++ (cpp)
```