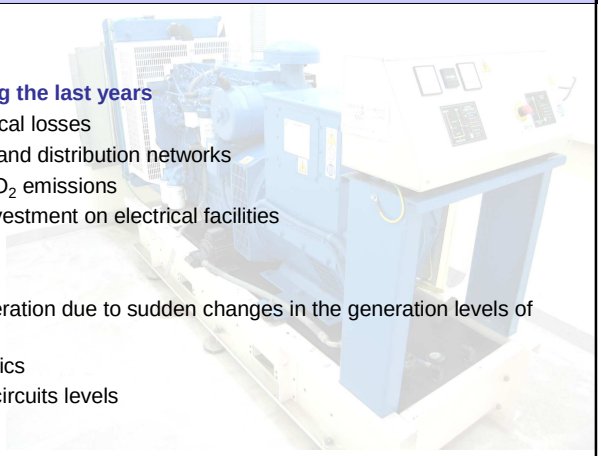
Microgrids

Outline:

- Introduction
- Proposed Control Strategies
- Experimental results
- Communications
- Experimental setup

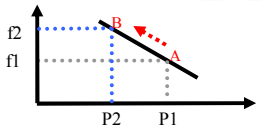
Introduction (I)

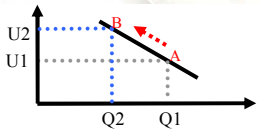


- Distributed Generation
  - **Drastic increase during the last years**
    - Reduction of electrical losses
      - Transmission and distribution networks
    - Reduction of the CO_2 emissions
    - Reduction in the investment on electrical facilities
  - **Unwanted problems**
    - Voltage regulation
    - Voltage flicker generation due to sudden changes in the generation levels of the DG
    - Increase of harmonics
    - Variations in short circuits levels

Introduction (II)

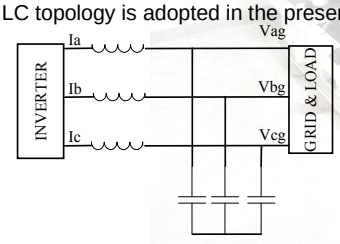
- Microgrid management philosophies can be roughly classified into three groups:
  - physical prime mover
  - virtual prime mover
  - distributed control
  - The most appropriate type of control is the distributed control as neither a central unit and communications are needed.
- Control of local state variables in distributed generation is commonly implemented in microgrid converters
  - **Control of microgrid converters:**
- Droop characteristic control:
  - P-f, Q-V





Introduction (III)

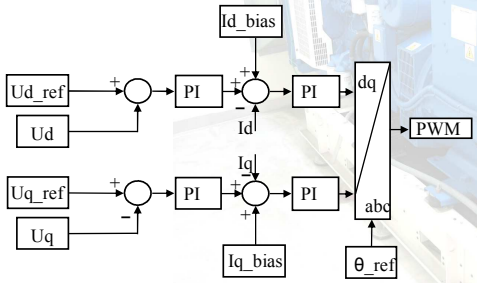
- Control of the microgrid converter variables
  - **The output of the converter is filtered with a resonant filter:**
    - Different filter topologies can be adopted
      - LC
      - LCL
    - The LC topology is adopted in the present research



    - The output converter current and the output filter voltage should be measured:
      - Voltage control
      - Power control

Proposed control strategies (I)

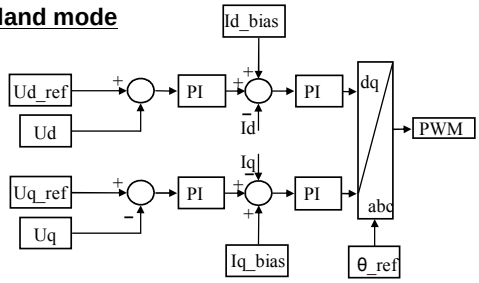
- Main control loop with classical PI regulators in a stationary reference frame for both island mode al grid connected mode



- **The feed forward currents are enabled only in grid connected mode**
  - varies the injected active and reactive power depending on the grid voltage magnitude and frequency, making a grid supporting labor

Proposed control strategies (II)

- **Island mode**



  - **Voltage calculation**

$$U_{d\_ref} = U_0^* + K_q (Q - Q_0)$$

  - **Frequency calculation**

$$f_{ref} = f_0^* + K_p (P - P_0)$$

Droop characteristic constants

$$K_q = \frac{U_{max} - U_0}{Q_{max} - Q_0}$$

$$K_p = \frac{f_{max} - f_0}{P_{max} - P_0}$$

Proposed control strategies (III)

- **Island mode**
  - **Conventional droop mode**

$$U_0^* = U_{rated} \qquad f_0^* = f_{rated}$$

  - **Power quality mode**

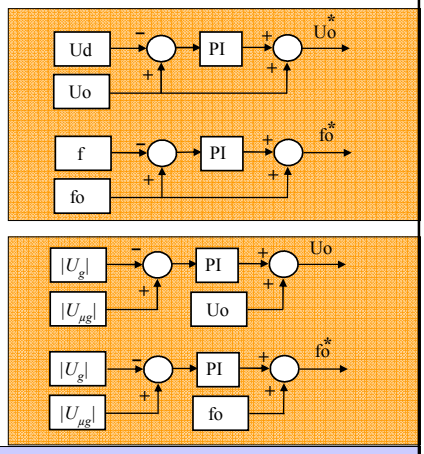
$$U_0^* = U_0 + PI \cdot (U_0 - U_d)$$

$$f_0^* = f_0 + PI \cdot (f_0 - f)$$

  - **Sync mode**

$$U_0^* = U_0 + PI \cdot (|U_{\mu g}| - |U_g|)$$

$$f_0^* = f_0 + PI \cdot (|\Theta_{\mu g}| - |\Theta_g|)$$



Proposed control strategies (IV)

- **Grid connected mode (Idq_bias are enabled):**
  - **Voltage and frequency references**
    - Continuously updated with the grid values

$$U_{d\_ref} = U_g \qquad f_{ref} = f_g$$

  - **Grid supporting mode**

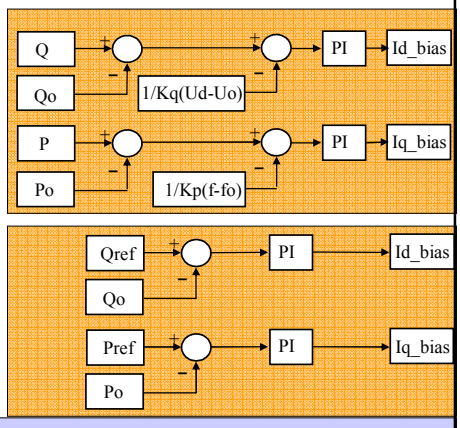
$$I_{d\_bias} = [(Q - Q_0) - \frac{1}{K_q}(U_d - U_0)] \cdot PI$$

$$I_{q\_bias} = [(P - P_0) - \frac{1}{K_p}(f - f_0)] \cdot PI$$

  - **Grid feeding mode**

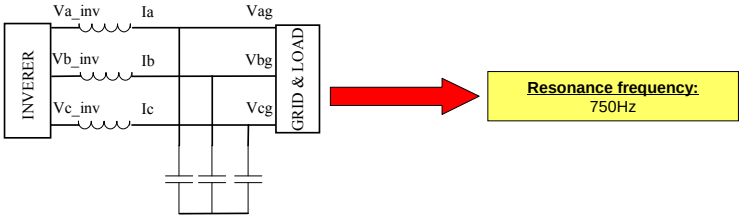
$$I_{d\_bias} = [(Qref - Q_0)] \cdot PI$$

$$I_{q\_bias} = [(Pref - P_0)] \cdot PI$$



Proposed control strategies (V)

- Main control loop using synchronous PI regulators
  - **Output filter of the converter (LC)**



  - **Model of the inductance filter in a synchronous reference frame**

$$\frac{di_d}{dt} = -\frac{R}{L} i_d + \frac{1}{L}(v_{invd} - v_d) + \omega i_q$$

$$\frac{di_q}{dt} = -\frac{R}{L} i_q + \frac{1}{L}(v_{invq} - v_q) - \omega i_d$$

Cross-coupling between *d* and *q-axis*

Proposed control strategies (VI)

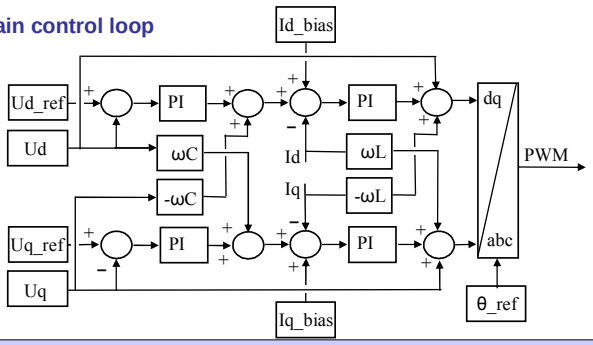
- Main control loop using synchronous PI regulators
  - **Model of the capacitor filter in a synchronous reference frame**

$$\frac{dv_d}{dt} = \frac{1}{C} i_{Cd} + \omega v_q$$

$$\frac{dv_q}{dt} = \frac{1}{C} i_{Cq} - \omega v_d$$

Cross-coupling between *d* and *q-axis*

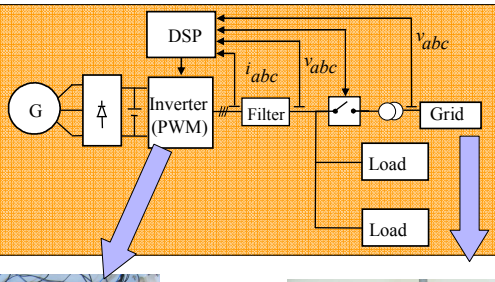
  - **Main control loop**

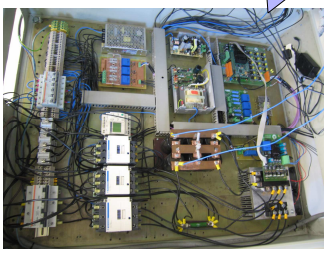


Experimental results (I)

- Experimental setup scheme

P (Kw)	100
V rated(V)	380
I rated (A)	152
ω rated (rpm)	1500
Pf	0.9

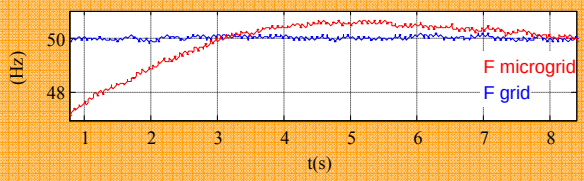




Experimental results (I)

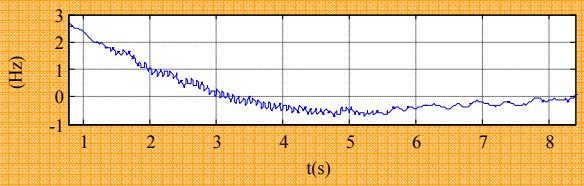
- **Synchronization:**

  - The synchronization time is desired to be as short as possible.
  - The frequency reference should be limited to avoid stability problems in the microgrid.
  - The frequency reference is limeted to fo +/-1Hz.



•Frequency error = 3Hz

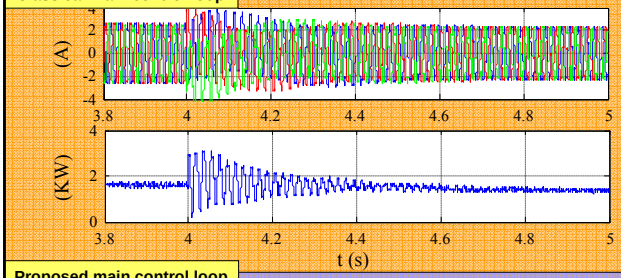
•Phase error = 180 elect. deg.



Experimental results (II)

- **Transition between sync-mode and grid connected mode:**

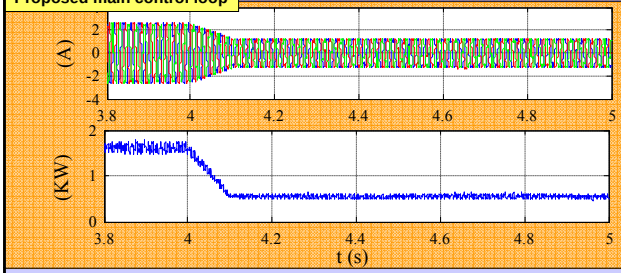
Classical main control loop



I_u, I_v, I_w } Converter currents

Converter active power

Proposed main control loop

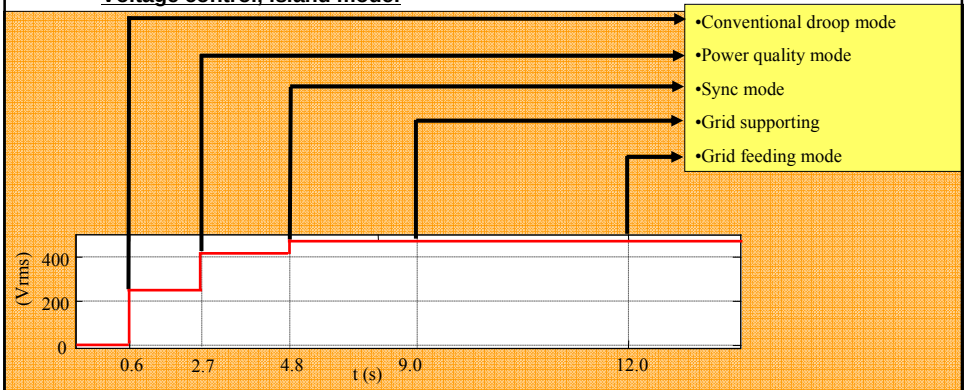


I_u, I_v, I_w } Converter currents

Converter active power

Experimental results (III)

- **Voltage control, island mode:**

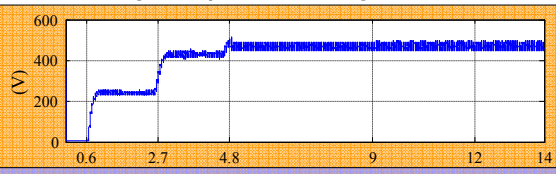


Load

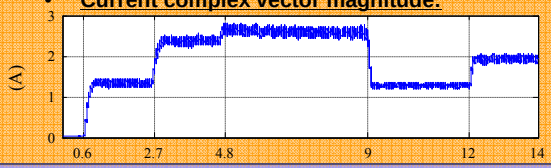
P (Kw)	1.35
V rated(V)	380
I rated (A)	3.55
Pf	1

Experimental results (IV)

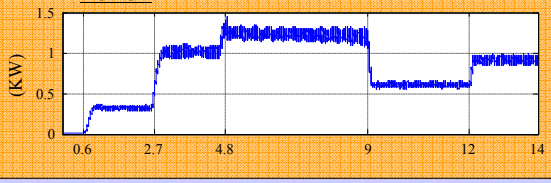
- **Voltage complex vector magnitude:**



- **Current complex vector magnitude:**



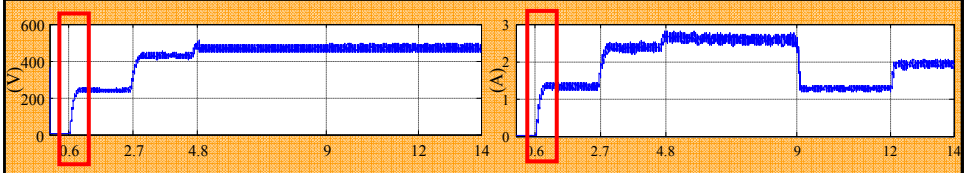
- **Power:**



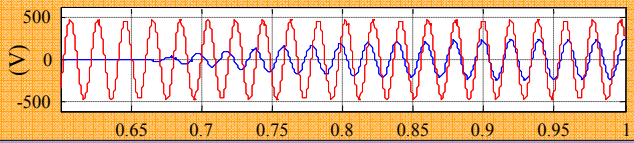
- Conventional droop mode (0.6<t<2.7)
- Power quality mode (2.7<t<4.7)
- Sync mode (4.7<t<9.0)
- Grid supporting (9.0<t<12.0)
- Grid feeding (t>12.0)

Experimental results (V)

- **Transient response when the conventional droop mode is activated:**

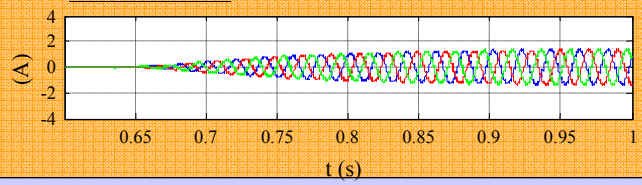


- **Phase voltage:**



Microgrid voltage
Grid voltage

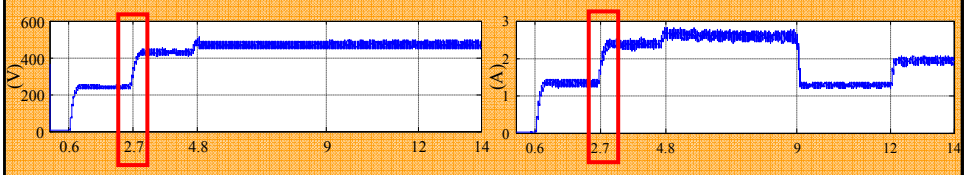
- **Phase currents:**



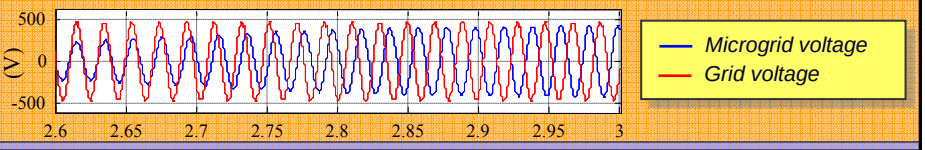
I_u
I_v
I_w

Experimental results (VI)

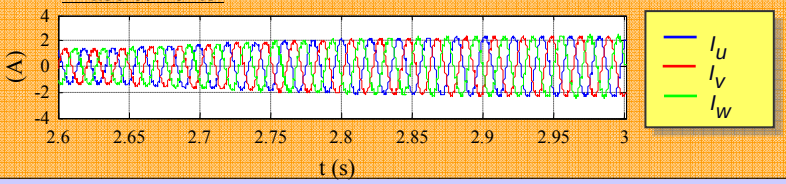
- **Transient response when the power quality mode is activated:**



- **Phase voltage:**

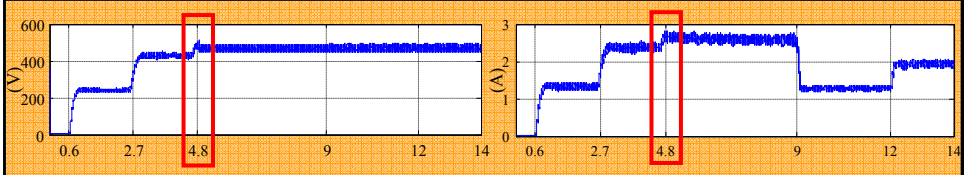


- **Phase currents:**

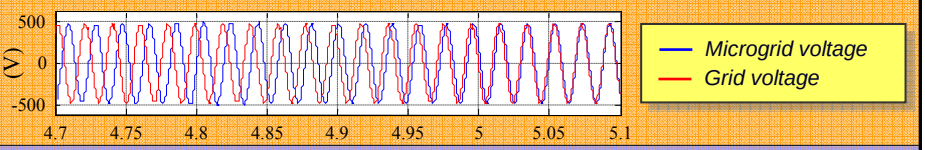


Experimental results (VII)

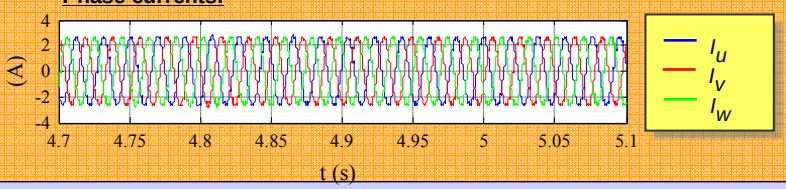
- **Transient response when the sync-mode is activated:**



- **Phase voltage:**

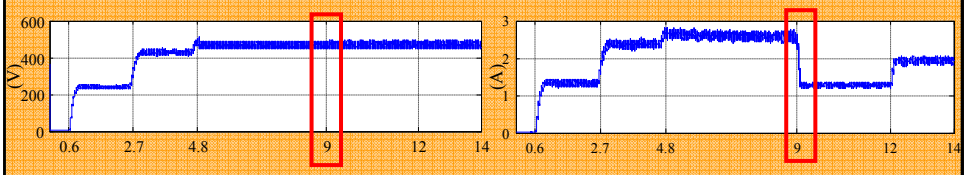


- **Phase currents:**

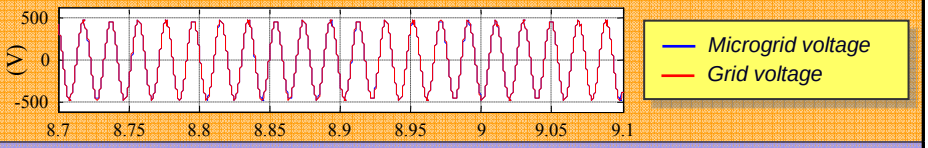


Experimental results (VIII)

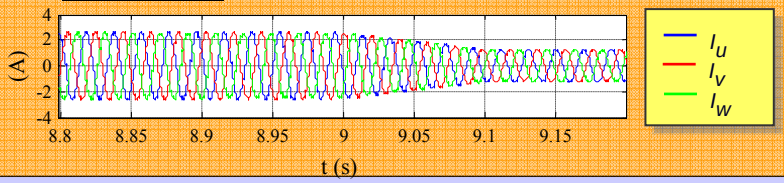
- **Transient response when the grid supporting mode is activated:**



- **Phase voltage:**

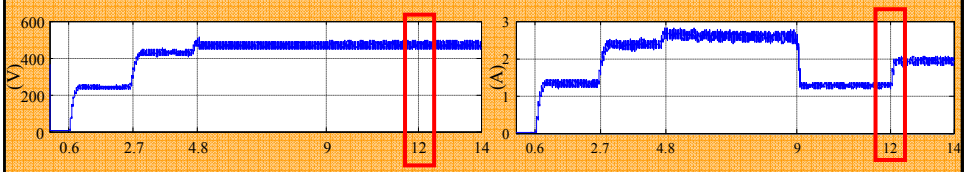


- **Phase currents:**

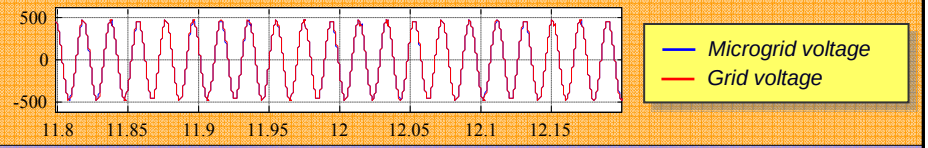


Experimental results (IX)

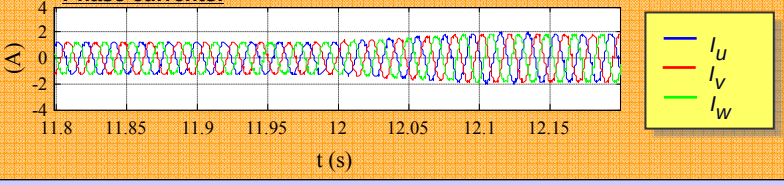
- **Transient response when the grid feeding mode is activated:**



- **Phase voltage:**



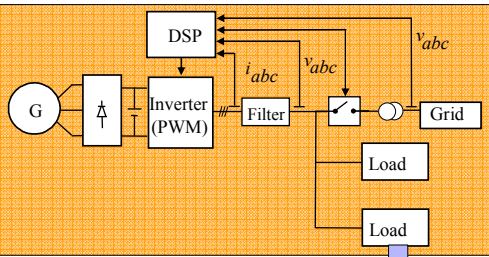
- **Phase currents:**



Experimental results (X)

- Experimental setup scheme

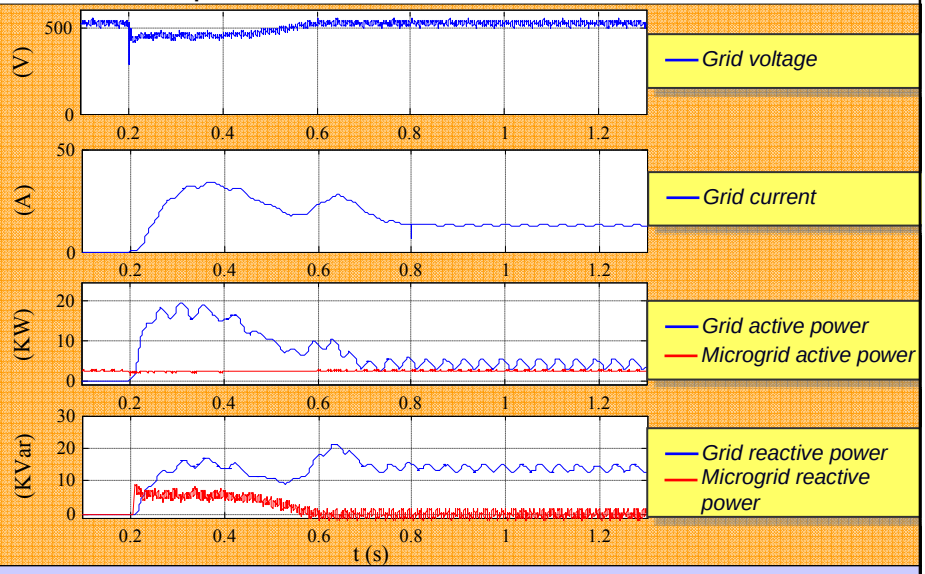
P (Kw)	100
V rated(V)	380
I rated (A)	152
ω rated (rpm)	1500
Pf	0.9



INDUCTION MOTOR PARAMETERS					
P_{rated} [KW]	V_{rated} [V]	I_{rated} [A]	f_{rated} [Hz]	n_{ated} [rpm]	Pf
2.5	380	6.9	50	1433	0.55
1.5	380	5.3	50	535	0.43

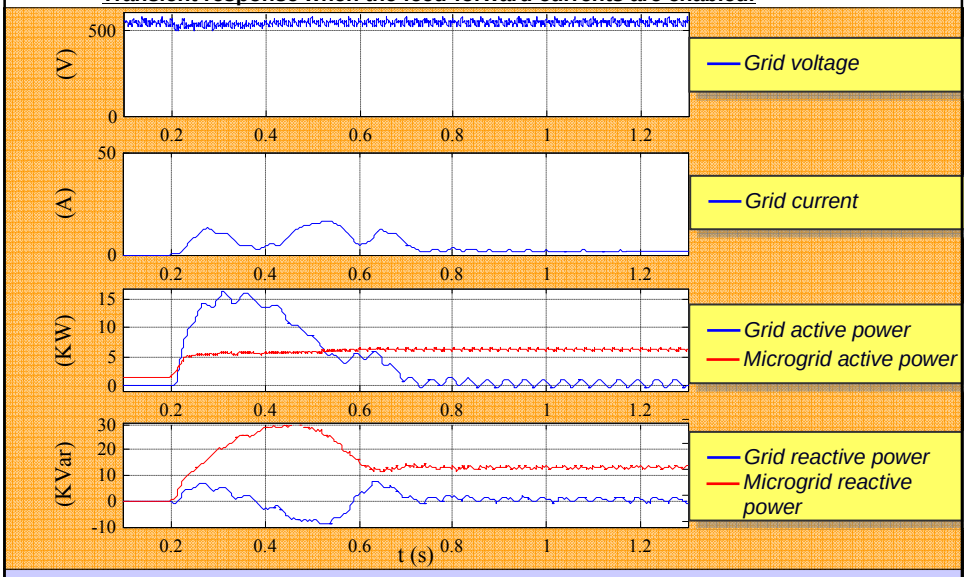
Experimental results (XI)

- **Transient response when the feed-forward currents are not enabled:**



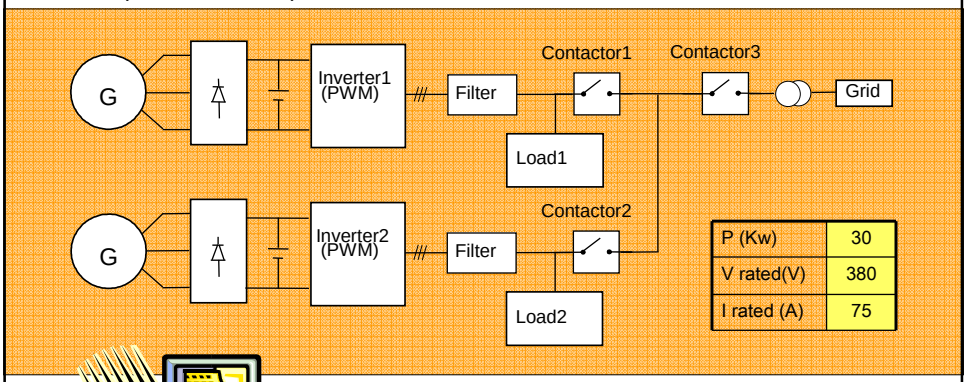
Experimental results (XII)

- **Transient response when the feed-forward currents are enabled:**



Parallel connected converters (I)

- Experimental setup scheme



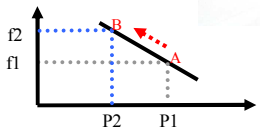
Sistema de comunicaciones:
- Control centralizado
- Situaciones de control multiagente

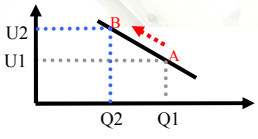
Communications

- SCI configuration
- Interruption routine
- Sending data function
- GUI

SCI Configuration

- Kp_droop
- Kq_droop
- Ud_ref
- Uq_ref





SCI Configuration

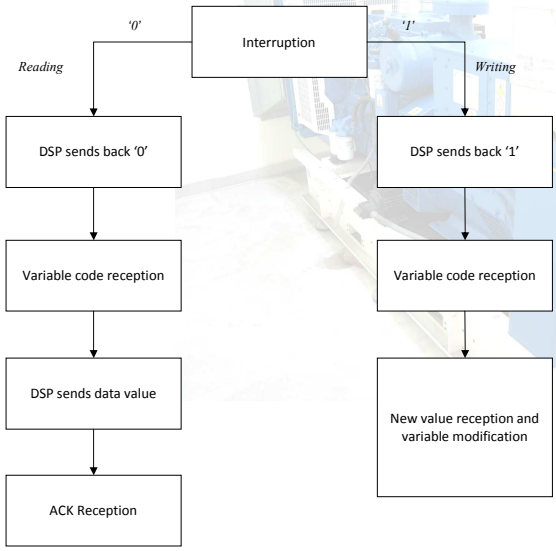
Configuration functions:

•*Scia_fifo_init()*

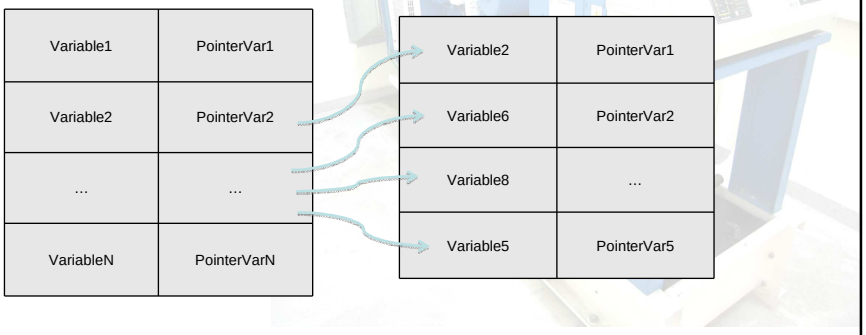
• *ConfigureSCI* (void(***interruptFCN**)(void),
SCI_PORT **SciPort**, SCI_SPEED **speed**, SCI_STOPBIT **StopBit** ,
SCI_PARITY **parity**, SCI_PARITY_ENABLE **SciParityEnable**,
Uint16 **nbit**)

Both functions are located in the library 'TIMotorLIB'

Interruption routine



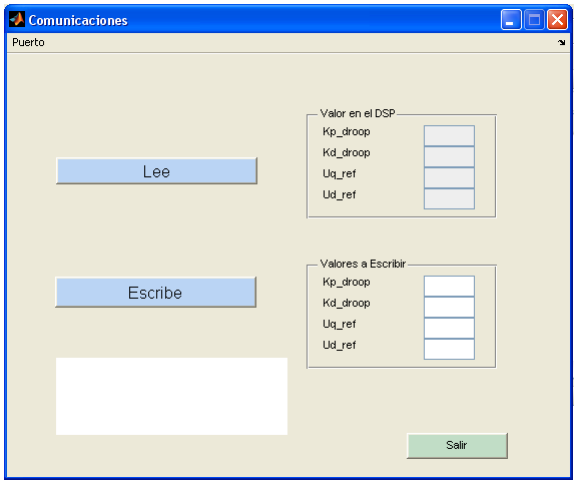
Interruption routine



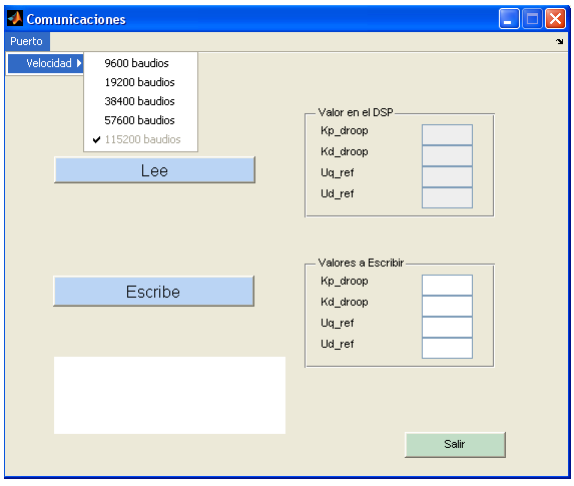
Sending data function

```
void send_data(Uint32 *a)
{
    int i;
    char num[4];

    for(i=0;i<4;i++)
        num[i] = 0;

    for(i=0;i<4;i++)
    {
        num[i] = (*a >> 8*i & 0x00FF);
        while (SciaRegs.SCIFFTX.bit.TXFFST != 0) {}      // TXFFST=0 -> fifo is empty,
                                                         //ready to transmit
        SciaRegs.SCITXBUF = num[i];
    }
}
```

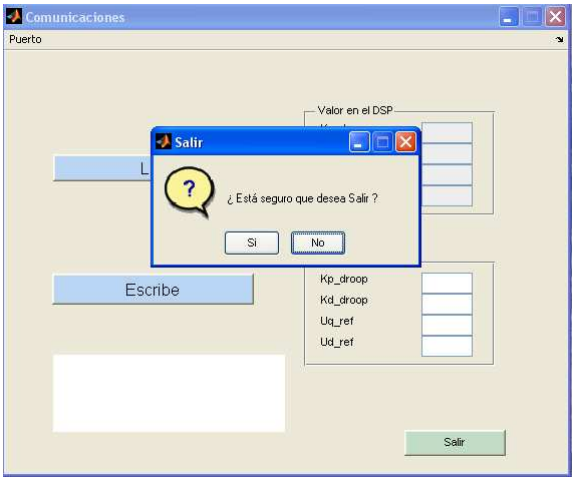
GUI (Graphical User Interface)



GUI (Graphical User Interface)



GUI (Graphical User Interface)



Disposición General

Vista general del sistema

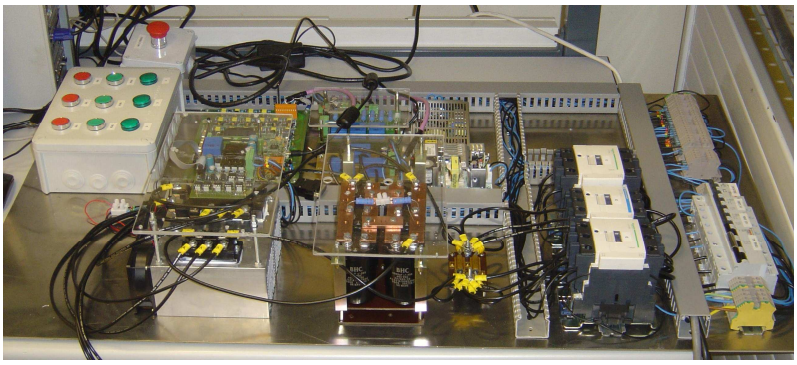
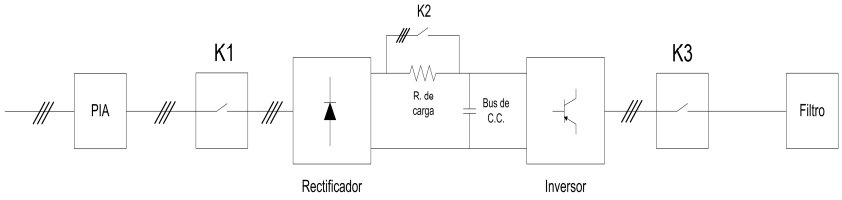
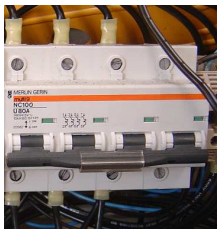


Diagrama Eléctrico



Elementos de Protección

- Protección trifásica:
  - PIA tripolar de 80 A



- Protección monofásica:
  - PIA bipolar de 10 A
  - PIA bipolar de 6 A

Elementos de Operación

- El sistema emplea, según configuración, entre 2 y 3 contactores:

  - Alimentación de entrada (80 A)

  - Anulación de la resistencia de carga (50 A)

  - Alimentación de salida (80 A)

Control de los contactores

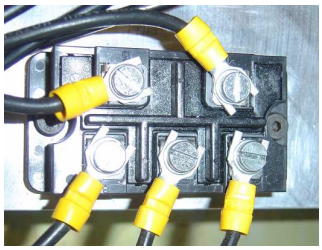
- Botonera fija / botonera móvil.
- Pulsadores de marcha y paro.
- Pulsador de paro de emergencia, retención mecánica, desbloqueo por giro.
- Indicadores luminosos de estado “marcha”.
- Interruptor de activación de pulsos.

Rectificador

- Funciones básicas:

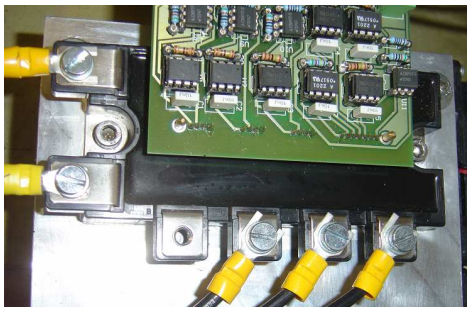
  - Trasforma la corriente alterna en conrriente continua.

  - Alimenta el bus de condensadores.



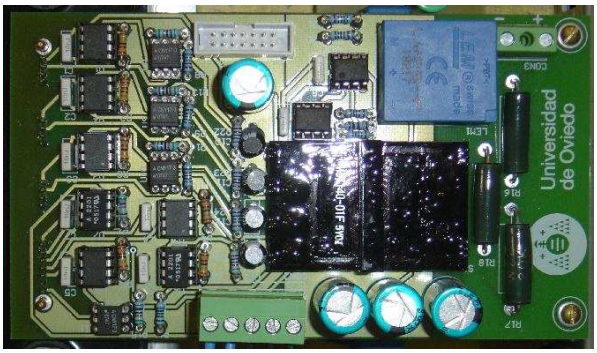
Inversor

- Transforma la corriente continua proporcionada por el rectificador en corriente alterna con que alimentar la microrred.
- Se controla mediante modulación PWM.



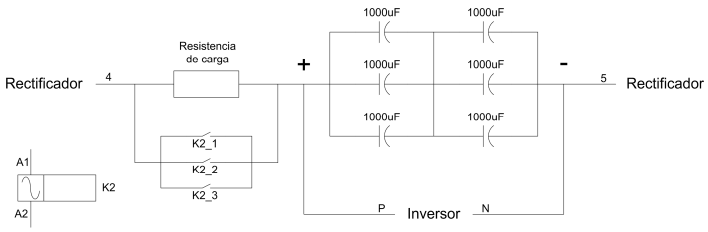
Placa de Aislamiento del Inversor

- Aisla electricamente el inversor del resto del sistema (optoacopladores).
- Se conecta a la placa de control y tratamiento de señales.



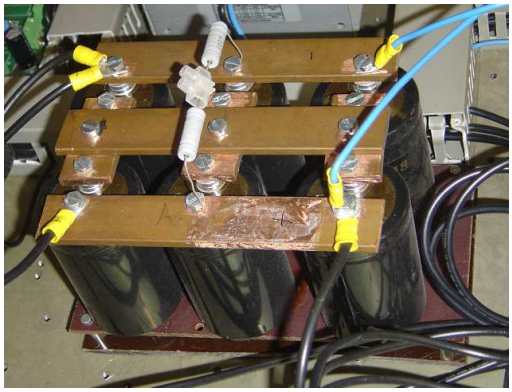
Bus de Corriente Continua

- Se trata de un bus formado por seis condensadores.
- Almacena energía en forma de tensión continua para proporcionar una alimentación estable al inversor.
- Durante la carga se conecta al rectificador a través de una resistencia de carga.
- Una vez cargado se anula dicha resistencia mediante un contactor conectado en paralelo a la misma.



Bus de Corriente Continua

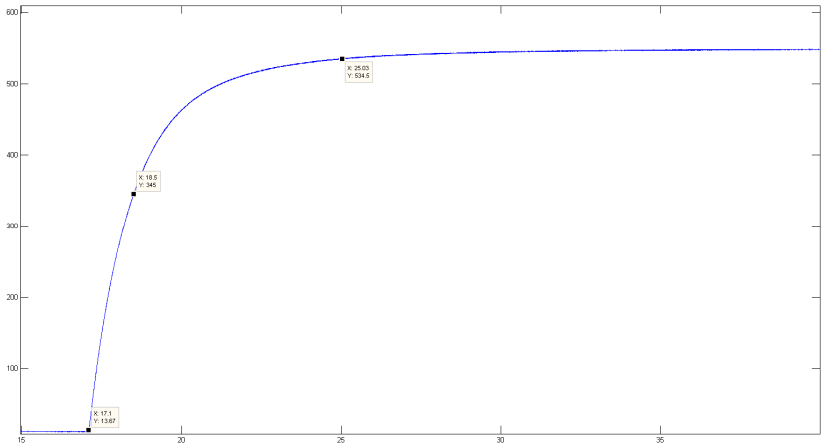
- **Aspecto físico**



Bus de Corriente Continua

Respuesta transitoria del circuito RC

R = 1 kΩ C_{eq} = 1500 µF T=1500 ms



Sensores

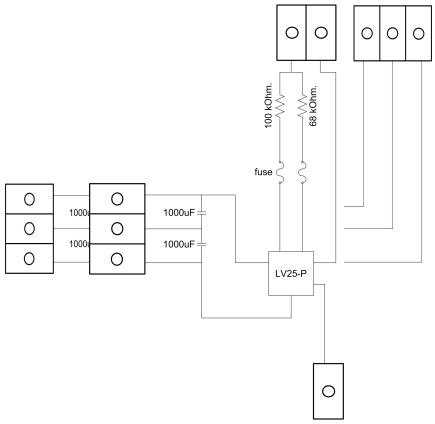
- El sistema emplea dos tipos de sensores:

  - Sensores de tensión: se emplean para medir la tensión de red y la tensión de salida del filtro del inversor(tensión de la microrred).

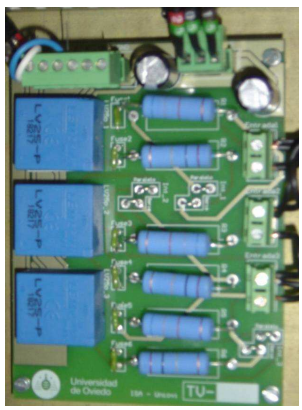
  - Sensor de corriente: mide la corriente de salida del inversor (corriente aportada a la microrred).

Sensor de Tensión

Esquema eléctrico:

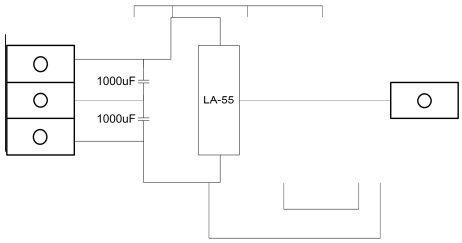


Aspecto físico:

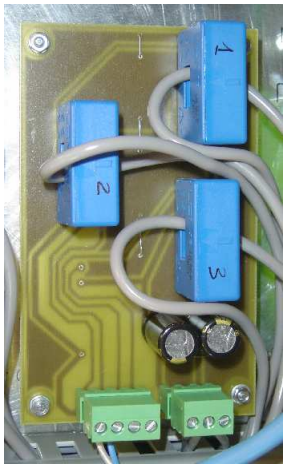


Sensor de Corriente

Esquema eléctrico:

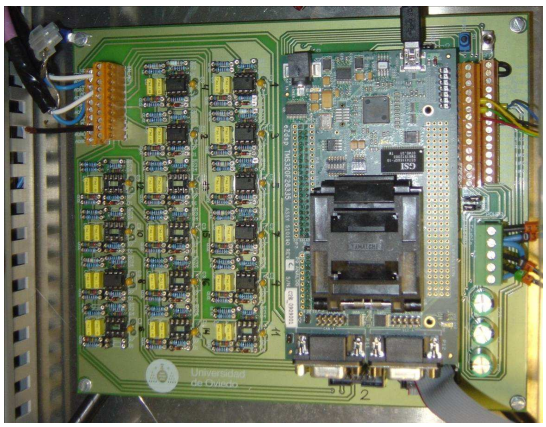


Aspecto físico:



Placa de Control y Tratamiento de Señales

Vista General



Placa de Control y Tratamiento de Señales

Funciones básicas

- Recibe la información proporcionada por los sensores.
- Adapta las señales a los niveles adecuados para enviarlas al DSP.
- Incorpora la electrónica de control del sistema
- Permite controlar hasta dos inversores
- Se completa con el DSP, directamente conectado a la misma.

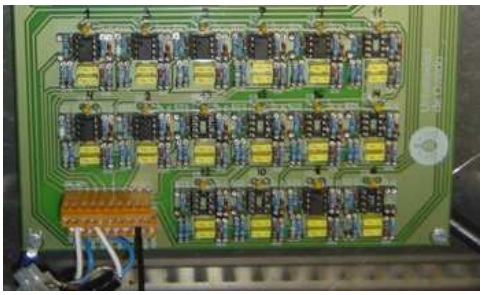
DSP

- Modelo TMS320 F28335.
- Frecuencia de operacion150 MHz.
- Chip de 32-bit en coma flotante.
- Conversor A/D de 12 bits y 16 canales de entrada.
- Tensión de alimentación: 5 Vdc.

Placa de Control y Tratamiento de Señales

CANALES DE FILTRADO

- Adaptación de niveles de tensión: 0-3.3 V
- Centrado de la onda: máxima resolución.



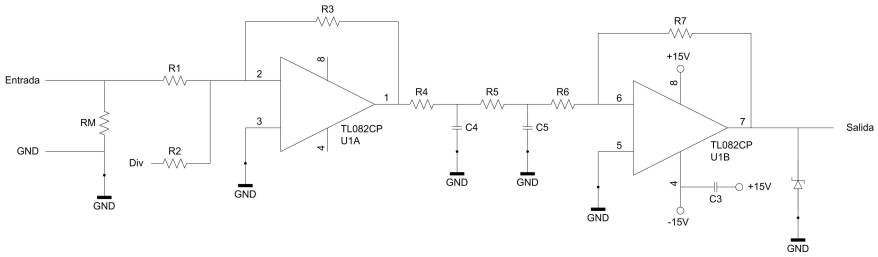
Placa de Control y Tratamiento de Señales

- Funciones:

  - Amplificación de la señal

  - Centrado de la señal en 1.5 voltios

- Esquema del circuito:



Alimentación de la cirtcuitería

- Las placas que conforman el sistema requieren distintos niveles de tensión continua para su funcionamiento, a saber: 5, 15, -15 y 24 V.
- Se emplean dos fuentes lineales conmutadas: una para la tensión de 24 V (ventiladores del disipador y placas de control de los inversores), y la otra para el resto de valores.