The European Association of Internal
Combustion Engine Manufacturers

EUROMOT

EUROMOT POSITION

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20 YEARS Promoting Engine in Society

Industrial Emissions Directive (2010/75/EU) – Start-up and shut-down periods for stationary Internal combustion engine plants

1. Introduction

The Industrial Emissions Directive 2010/75/EU (IED) requires the establishment of implementing rules concerning the determination of start-up and shut-down rules for combustion plants in Article 41 (1). EUROMOT actively participated and supported the process which led to the adoption of the Commission Implementing Decision (2012/249/EU) of 7 May 2012 "concerning the determination of start-up and shut-down periods for the purposes of Directive 2010/75/EU of the European Parliament and of the Council on industrial emissions" /1/.

The emissions from combustion plants during start-up and shut down periods are generally at elevated concentrations (e.g. catalyst temperatures are too cold in the start-up phase for efficient emission reduction performance) compared to "normal operating conditions" therefore the Industrial Emissions Directive excludes start-up and shut-down from the definition of operating hours (Article 3 (27)) and requires Member States to include measures regarding start-up and shut-down periods in the permits in order to reduce emissions (Article 14 (1f)). In the preface (item 4) of the Commission Implementation Decision (2012/249/EU) is stated "*In view of the objective of Directive 2010/75/EU to prevent emissions, those periods should be **as short as possible***",

2. Start-up and shut-down periods in different power plant types

Gas fired RICE (Reciprocating Internal Combustion Engine):

In order to fulfill the strict emission limits set in Annex V of the IED, internal combustion gas engine plants have to apply secondary emission abatement techniques, such as Selective Catalytic Reduction

(SCR) combined with oxidation catalysts technology. The start-up operations of internal combustion engines before reaching steady operation are characterized by low catalyst temperatures, varying exhaust temperatures (cold engines) and fluctuating/transient load conditions. Similarly, during shut-down procedures the load conditions are fluctuating/transient. If the catalyst temperature is too low, below the catalyst operating temperatures, the catalysts will not be fully operational and will not work efficiently to reduce emissions. Start-up times and emission levels from internal combustion engines will greatly vary depending on a cold or hot start. In a **cold start** (engine typically been standby 20 hours or more), it can take typically up to 30 minutes, before the temperature is high enough for the large catalysts needed for engine units above 15 MWth to start reducing emissions (see typical temperature profile of a catalyst during a cold start up of a big gas engine in annex 1 of this document /2/). If the catalysts are already hot (in a **hot start up**, single cycle engine typically been standby 5 hours or less) typically above > 200 degree C before start-up procedures begin, the start-up time can be considerably shorter down to a typically minimum of 15 minutes.

Coal plant, Combined Cycle Gas Turbine (CCGT):

According to /3/ the emission control functioning in coal fired units **can** take up to 6 hours after start of electricity production. Hot start conditions for CCGTs vary somewhat by manufacturer, maintaining energized electrical systems, „purge credit“, and steam temperature control enable CCGT startup times of about 30 to 35 minutes from initiation of the start sequence. This is about half the time for conventional **hot start** that would require purge and gas turbine holds /4/.

3. Emission measurement during start-up and shut-down.

Emissions in power plants today are measured at steady state conditions and in our opinion there are no available and repeatable test methods or procedures for measuring emissions during the transient load ramp found during start-up and shut-down. Necessary start-up/shut-down periods can vary significantly depending on the type/size of engine, catalyst composition/volume, fuel (gas/liquid), ambient conditions, application and rated load (see below for more information). It is important that an emission measurement standard has to be tied to a validated, accurate, repeatable and cost-effective test method. When set loading point is reached the engine operation is still to be stabilized before emission measurements (at isokinetic conditions, etc.) are conducted. IED 2010/75/EU clearly excludes start-up (SU) and shut-down (SD) periods from the average emission limit values calculation procedure in Annex V Part 4 “Assessment of compliance with emission limit values” text in end of item 1. In below text more information is given supporting the rationality of this IED approach in regard of exclusion of SU/SD **periods from** the emission compliance process.

During engine start-up operations, engine and catalyst temperatures are low, engine flue gas temperature varying as well as engine speed and load conditions are both transient and very low. In this respect, engine start-up can frequently consist of operation at idle for some period of time before a load representative of the engine's intended use is applied to the engine. A necessary corollary is that the emissions profile of an engine during start-up operations also will be fundamentally dissimilar to the emissions profile of an engine operating at the speed and load points that are typical for its intended application and work. The other basic functional aspects of the engine's operations -- including engine speed, load, fuel consumption, efficiency and output --will be fundamentally different as well. Emission measurement challenges are:

- The measured emission values during a transient vary greatly and obtained results will contain **big uncertainties**:
  - Volumetric measurements are not representative for the total SU/SD emission as the duration of these excursions is short and flue gas flows are transient well below steady state values. Consequently the emission reference O_2-point will also vary greatly, making the reference comparison calculations very difficult.

- **No formal or approved test protocol** exists currently for SU/SD quantification:
  - Integrated measured ppm-v with exhaust flow rate is needed to determine kg/event emission values.
  - Thus during these limited time periods, the measured emission values (in ppm-v or mg/Nm^3) might vary in a broad range and thus require use of multiple analyzers and ranges
  - Transient air flows, exhaust gas composition (O_2-concentration) and temperatures will also complicate measurements.

- Response time (especially for CEMS) and/or test methodology might limit the ability to accurately represent the transient nature of SU/SD emissions.

Then, in addition to there being no test procedure, there also are no data on which to premise a numerical emission standard for RICE start-up/shut-down operations.

EUROMOT therefore recommends reporting and permits for SU/SD emission in estimated mass per event (kg/event). This enables also the necessary annual reporting as required by Article 72 (3) in IED 2010/75/EU.

4. Implementing start-up and shut-down rules for engines

On 7 May 2012, the EU commission published an implementing decision concerning definition on start-up (SU) and shut down periods (SD) for purposes of IED (2012/249/EU). The IED does not foresee any numerical emission limit values for start-up and shut-down periods, instead the **emissions are minimised by defining and limiting these periods while simultaneously safeguarding health and safety aspects.**

According to Article 9 of the the implementing decision, the determination of SU/SD periods has to be based on at least three criteria chosen from the operational parameters and discrete processes or other equivalent parameters which suit the technical characteristics of the plant. The discrete processes and operational parameters are listed in the Annex of the Implementing Decision /1/. The end of SU or SD is reached when at least two of three criteria have been met.

As **no** discrete process has been defined for stationary RICE in the final Commission Implementation Decision document, operational **discrete parameter** has to be set for engines in order to ensure similar treatment compared to other prime movers such as solid/liquid fired boilers and gas turbine. EUROMOT recommends setting following parameter as a „ *equivalent processes that suit the technical characteristics of the plant*“ (this **was actually included** in previous working (Commission Implementation Decision) documents as item “d)” until February 2012) :

*"1.4. **For engines, instead of discrete combustion processes a start-up period which is a fixed time period may be applied** "*

A chronologic or time based factor is also in fact used today in USA, Cyprus, Malta and Greece for stationary reciprocating internal combustion engines (RICE) /2/. US EPA has in the NESHAP /5/ ruling limited the start-up period as: “*Owners and operators must minimize the engine’s startup period to the amount of time needed for appropriate and safe loading of the engine, not to exceed 30 minutes. After this time, the engine must meet the numerical emission standards, if applicable “.*

As the discrete process / operational parameter list of the Annex of the EU Commission Implementing Decision concerning definition on start-up (SU) and shut down periods (SD) for purposes of IED (2012/249/EU) is insufficient we propose addition of following „ *equivalent operational parameters that suit the technical characteristics of the plant*“ for RICE:

<u>Start-UP</u> Discrete process <u>(for set point see Annex 2, page 1):</u>

- **<u>1.4a) Maximum time from engine start up signal”</u>**

<u>Start-UP Operational Parameters (for set points & subheaders see Annex 2, page 1):</u>

- **2.2a) Stable exhaust gas temperature after turbo charger (TC)**
- **2.2b) Minimum exhaust gas temperature[3] after catalyst system**
- **2.2c) Minimum time for system stabilizationafter urea injection/ammonia. Injection starts and exhaust gas temperature has reached normal operating temperature, typically 280 – 350 degree C after catalyst system[4].**
- **2.5a) Minimum stable operation time above optimal load[1] limit. Generator terminal output, shaft torque or fuel flow rate specified as a percentage of continuous power figures[2].**

<u>Shut-Down Discrete Process / Operational Parameters (for set points see Annex 2, page 1)</u>:

- **2.5b) Engine shut down or emergency shutdown activated**
- **1.4b) Maximum time before fuel interruption to engine**

In Annex 2 page 2 is given an example **“RICE equipped <u>with SCR</u>, cold start”** how to apply above proposed discrete process and operational parameters.

<u>Explanation of above case in ANNEX 2 page 2</u>:

- Discrete process parameter 1.4): “Maximum time from engine start up signal – **30 minutes**”
- Operational parameter 2.5 a): “Minimum stable load above optimal load[1] limit . Generator terminal output, shaft torque or fuel flow rate specified as percentage of continuous power figures[2] – “**10 minutes minimum stable operation time above optimal load reached**” **<u>i.e. after 24 minutes”.</u>**

- Operational parameter 2.2 c): “Minimum time for system stabilization after urea injection, urea injection starts and exhaust gas temperature has reached normal operating temperature typically 280 – 350 degree C after catalyst system[4]” – “**5 minutes after urea injection started” i.e. after <u>28 minutes</u>”**

Resulting time parameters 2.5 a) - **24 minutes** and 2.2 c) – **28 minutes** shorter than 1.4) - **30 minutes**. - “***Make the start-up and shut-down periods as short as possible without compromising health and safety aspects“*** approach → **<u>Start-up time 28 minutes</u>**

- ***[1] The performance of a reciprocating engine is optimal above 85% of the continuous power output***
- ***[2] Continuous power (COP) defined ISO 8528-1:2005(E)***
- ***[3] Set point dependent on design temperature for specific system, typically > 300° C***
- ***[4] Set point dependent on SCR design temperature for specific fuel quality, typically 280-350 °C***

5. Conclusion

It is expected that in future power systems combustion power plants will start and stop significantly more frequently than in the past due to the cyclic operation mode caused by renewable power sources such as solar and wind. In Annex 4 installed capacity (has increased strongly during last years) of solar and wind in EU 27 are shown. Fast starting and stopping non spinning reserve power plants are more efficient and have thus a better total outcome on the system level than spinning reserve capacity plants kept operating on (inefficient) part loads in order to be ready to cover power transient needs in the electrical grid.

In the EU Commission Implementation Decision /1/ the start-up (SU) and shut-down (SD) periods for the purposes of Directive 2010/75/EU are defined. Target is that these periods should be <u>as short as possible in order to limit emissions</u> (i.e. measures ensuring that **emission secondary** abatement equipment is brought into **<u>operation as soon as this is technically practicable</u>**). Criterias for these periods are to be based on transparent and externally verifiable parameters. The determination of SU and SD periods shall be based on conditions allowing a stable generation process <u>safeguarding health and safety</u> **<u>aspects</u>**. **In the SU/SD determination: operational parameters or discrete processes in the annex of the document /1/ or equivalent processes/operational parameters that suit the technical characteristics of the plant shall be used**. **The end of SU or SD is reached when at least two of three criteria have been met.**

In above text ***equivalent discrete processes/operational parameters that suit the technical characteristics*** **of the stationary RICE gas plant have been given in order to fulfil the EU Commission Implementation Decision /1/:** ***make the start-up and shut-down periods as short as possible without compromising health and safety aspects***. **In Annex 2 an example how to use these are given.**

The operational parameters and especially set points are to be checked with the stationary RICE plant supplier in each case.

6. Sources

/1/EU Commission Implementing Decision on Start-UP/Shut-Down (SU/SD) at
http://www.emissions-euets.com/attachments/203_Commission%20Implementing%20Decision%20-%20determination%20of%20start-up%20and%20shut-down%20periods.pdf

/2/ Euromot Position Paper dated 13 September 2011 at internet address:
http://www.euromot.org/download/b6244cfb-47f7-4f71-bd1c-c28d6ec3ab3e/EU%20IED%20start-up%20-%20shut-down%20definition%202011-09-13.pdf

/3/ "Assessment of startup period at coal-fired electric generating units ", US EPA June 17, 2013 at: http://www.epa.gov/mats/pdfs/matsstartstsd.pdf

/4/ http://www.wartsila.com/en/reciprocating-engine-vs-gas-turbine-startup-time

/ 5 / "New Requirements Finalized in RICE NESHAP" at:
http://www.trinityconsultants.com/Templates/TrinityConsultants/News/Article.aspx?id=2643

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For more information please contact:

European Association of Internal Combustion
Engine Manufacturers – EUROMOT
Paul Zepf, (+49 69) 6603-1752, paul.zepf@euromot.eu
EU Transparency Register ID number: 6284937371-73

ANNEX 1

Typical Catalyst Heat Up Curve for a big catalyst unit

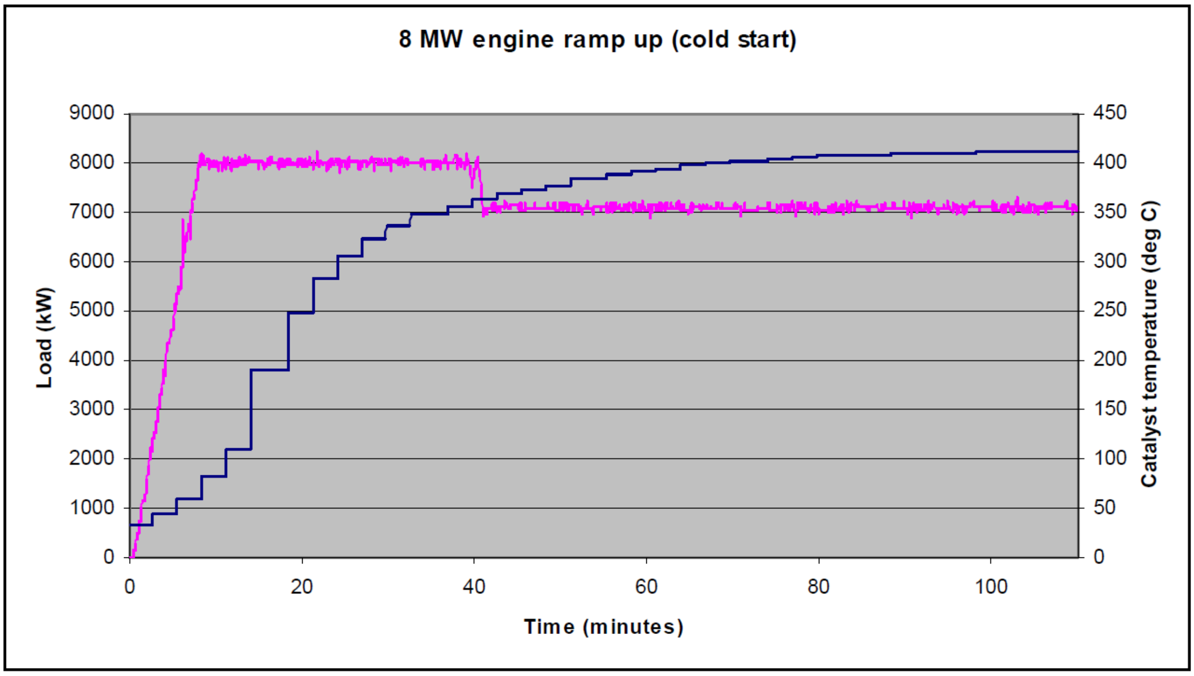


Figure 1. Load/Temperature Start-Up Profile

Temperature

Load

<u>ANNEX 2 (1/2)</u>

<u>Proposal</u> for "*equivalent processes (discrete /operational parameters) that suit the technical characteristics"* of the Stationary RICE plant

"<u>At least three criteria shall be defined</u>, with the end of start-up or start of shut-down periods reached when <u>at least two of the criteria have been met</u>. The criteria shall be chosen from the following: discrete processes .. / operational parameters set out in the Annex <u>or equivalent processes that suit the technical characteristics of the plant</u>"

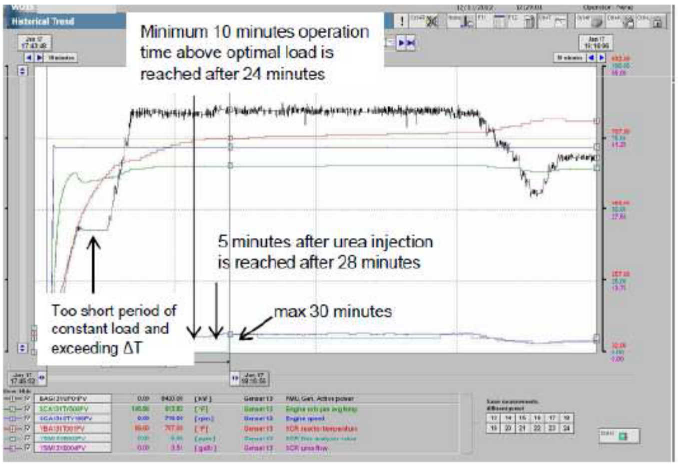
Technique	IED ANNEX paragraph	Parameter or process	Set point	unit
Reciprocating engine	2.2 a)	Stable exhaust gas temperature after turbo charger.	± 2	℃/ 5 min
	2.5 a)	Minimum stable operation time above optimal load[1] limit. Generator terminal output, shaft torque or fuel flow rate specified as a percentage of continuous power figures[2].	10	[min]
	1.4 a)	Maximum time from engine start up signal	30	[min]
Reciprocating engine with oxidation catalyst	2.5 a)	Minimum stable operation time above optimal load[1] limit. Generator terminal output, shaft torque or fuel flow rate specified as a percentage of continuous power figures[2].	10	[min]
	2.2 b)	Minimum exhaust gas temperature after catalyst system	300 [3]	[°C]
	1.4 a)	Maximum time from engine start up signal	30	[min]
Reciprocating engine with selective catalystic reduction (SCR) or combined catalyst system	2.5 a)	Minimum stable operation time above optimal load[1] limit. Generator terminal output, shaft torque or fuel flow rate specified as a percentage of continuous power figures[2].	10	[min]
	2.2 c)	Minimum time for system stabilisation after urea injection. Injection starts and exhaust gas temperature has reached normal operating temperature, typically 280-350 ℃ after catalyst system[4]	5	[min]
	1.4 a)	Maximum time from engine start up signal	30	[min]

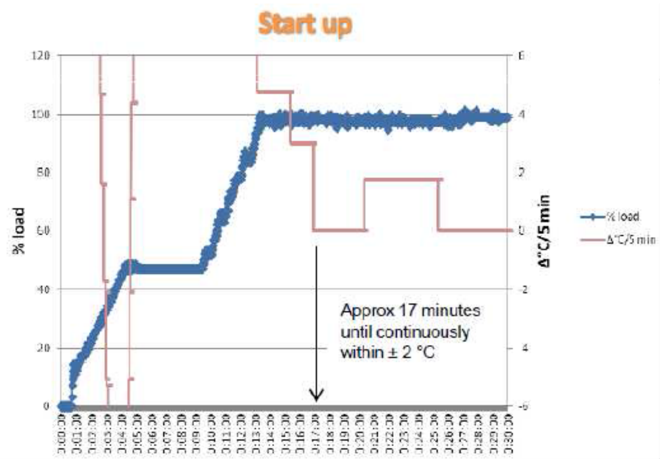
[1] The performance of a reciprocating engine is optimal above 85% of the continuous power output
[2] Continuous power (COP) defined ISO 8528-1:2005(E)
[3] Set point dependent on design temperature for specific system, typically > 300° C
[4] Set point dependent on SCR design temperature for specific fuel quality, typically 280-350 °C

Technique	IED ANNEX paragraph	Parameter or process	Set point	unit
Reciprocating engine	2.5 b)	Engine shut down or emergency shutdown command activated		
	1.4 b)	Maximum time before fuel interuption to engine.	5	[min]

ANNEX 2 (2/2)

Example	IED ANNEX paragraph	Parameter or process	Criteria reached [min]
Reciprocating engine	2.2 a)	Stable exhaust gas temperature after turbo charger.	17
	2.5 a)	Minimum stable operation time above optimal load[1] limit. Generator terminal output, shaft torque or fuel flow rate specified as a percentage of continuous power figures[2].	24
	1.4 a)	Maximum time from engine start up signal	30
Reciprocating engine with selective catalystic reduction (SCR) or combined catalyst system	2.5 a)	Minimum stable operation time above optimal load[1] limit. Generator terminal output, shaft torque or fuel flow rate specified as a percentage of continuous power figures[2].	24
	2.2 c)	Minimum time for system stabilisation after urea injection. Injection starts at exhaust gas temperature typically 280-350 ℃ after catalyst system [4]	28
	1.4	Maximum time from engine start up signal	30





ANNEX 3

(Commission Implementation Decision 2012/249/EU) ANNEX

DISCRETE PROCESSES AND OPERATIONAL PARAMETERS ASSOCIATED WITH START-UP AND SHUT-DOWN PERIODS

1. **Discrete processes associated with the minimum start-up load for stable generation**

1.1. For solid fuel-fired boilers: complete transition from using the stability auxiliary burners or supplementary burners to operating with normal fuel only.

1.2. For liquid fuel-fired boilers: start of the main fuel feed pump and when burner oil pressure stabilises, and for which fuel flow rate may be used as an indicator.

1.3. For gas turbines: point where the combustion mode switches to fully premixed steady state combustion mode, or 'idle speed'.

2. **Operational parameters**

2.1. Oxygen content of the flue gases.

2.2. Flue gas temperature.

2.3. Steam pressure.

2.4. For heat producing plants: enthalpy and heat transfer fluid rate.

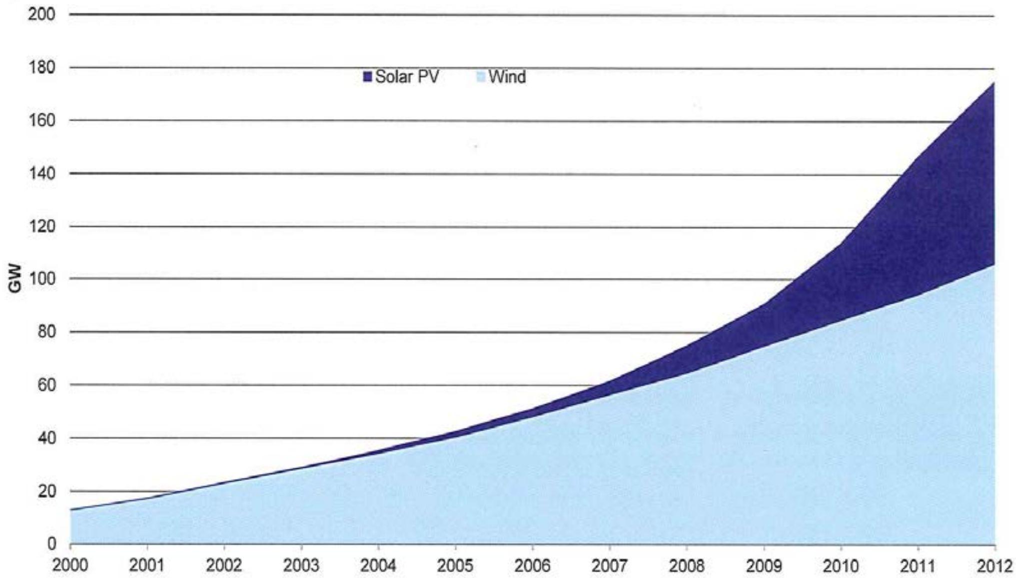
2.5. For liquid and gas fired plants: fuel flow rate, specified as a percentage of the rated fuel flow capacity.

2.6. For steam boiler plants: temperature of steam at the exit of the boiler.

ANNEX 4

5) Wind and Solar in EU 27

Source: *European Wind Energy Association (EWEA)*, European Photovoltaic Industry Assiciation (EPIA).



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