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# Optimal Thermal Regulation of a Real Data Centre

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**Abstract:** This paper presents a pilot method for optimal temperature regulation of real data centre rooms. The development is a part of a wider research activity conducted for EU FP7 project GENiC (Globally optimized Energy efficient data Centres). An overall description of the concept and GENiC platform is presented with emphasis on the thermal control system development including its architecture, design, online-algorithms and real system implementation on a real data centre facility. Latest experimental results of the developed control platform are presented, illustrating the capabilities and efficiency of the proposed technical approach towards optimal thermal control of data centres.



*Keywords:* Industrial applications of optimal control, Adaptive control, Time-varying systems

## 1. INTRODUCTION

Optimizing DC energy efficiency and improving operational performance is becoming critical due to incremental needs in IT processing and energy related carbon emission reduction goals imposed by regulation authorities. For that reason, optimal energy usage is a major challenge for DCs operators and a driver to advance the development on effective energy management and optimal control systems, using renewable energy sources (RES) and smart grid technologies. DCs energy consumption depends on multiple factors which could influence the energy management solutions. Some of these factors are: Energy prices depending on the country, types of energy supplies, number of suppliers, etc.; Weather conditions where temperature and humidity have impacts on the effectiveness of heating-ventilation-and-air-conditioning (HVAC) systems; Geographical location, where different type of RES and grid configuration are available; DC load and usage depending on DC customers. Taking into consideration the above factors, minimising the energy consumption of a DC would require real time monitoring of multiple information, data processing and finally optimal control and decision making supervisory systems. In order to save energy and increase the performance of DCs, a unified energy management system must efficiently distribute and assign IT workload to multiple servers and optimally coordinate cooling equipment to achieve required thermal profiles inside the DC rooms (Li et. al. 2012). In addition, optimal coordination of electrical power provided by Renewable Sources (RES), storage and the grid contributes towards meeting energy savings DC operational cost goals.

Research and development activities for the above topics were conducted in project GENiC (Globally optimized Energy efficient data Centres) funded by the EU FP7 research, technological development and demonstration program 608826. The above research included concept generations, feasibility tests and finally the development and demonstration of a scalable, to any DC in principle, optimal energy management platform for efficient DC control. Within the GENiC project a distributed platform has been developed and deployed on a real data centre facility. The above platform hosted multiple services related to the control and management of IT workload, thermal regulation and power usage of the DC, ensuring satisfactory DC performance compliant to system level requirements and specifications. It is worth mentioning that the resulted technology aimed to be scalable to real-life DC facilities, agile to adapt to evolved DC dynamic environments, and finally not tied to specific DC info structures (e.g. equipment/space topology, functional structure). The GENiC platform has been successfully deployed and demonstrated to a real DC facility at Cork Institute of Technology (CIT) at Cork in Ireland. Limited access to real multiple DC sites at present has prevented tests of GENiC at multiple facilities.

This paper focuses on the thermal management services developed within the GENiC project, for optimal thermal regulation of DCs server rooms. Because server IT workload is the main cause of thermal irregularities and undesired temperature hotspots inside the DC rooms, efficient thermal profile regulation across DC rooms, via optimal coordination and commanding of available cooling equipment is of major importance. The contents of this paper are as follows. In section 2, the overall GENiC system platform is briefly described with focus on the thermal management component and its design. Section 3 presents the technical details of thermal modelling and prediction process. The thermal control algorithm is presented next in section 4. Regarding the real system application, the integration of the GENiC thermal components, described in sections 3 and 4, including real time system monitoring, closed-loop control, and respective system experimental results are discussed in section 5. Finally, some conclusions are synopsised in section6. Throughout the paper standard notation is adopted. In particular, $\mathsf{N}$, $\Re$ denote the sets of natural, real numbers. $\mathsf{N}_*$ is $\mathsf{N}$ excluding zero and $\Re^n$, $\Re^{n\times m}$ denote the spaces of


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real $n \times 1$ vectors, $n \times m$ matrices respectively. $\otimes$ denotes matrix Kronecker product. $vec(\cdot)$ is a vector formed from the columns of a matrix and $vec^{-1}(\cdot)$ forms back the original matrix column wise. $\boldsymbol{I}$, $\boldsymbol{0}$ are identity, zero matrices of appropriate dimensions and $:=$ means equal by definition.

## 2. GENiC PLATFORM

### *2.1 System architecture*

The GENiC concept is categorising the operational behaviour of a DC into three fundamental clusters: a) IT server workload executed by the DC servers, b) thermal temperature distribution of the DC room and c) electrical power demand and supply of the DC. The optimal coordination and cooperation of the above is managed in order to achieve several energy goals. The GENiC architecture, shown in Fig. 1, consists of multiple system components, where individual system optimization tasks are assigned in order to achieve optimal system operation and energy efficiency.

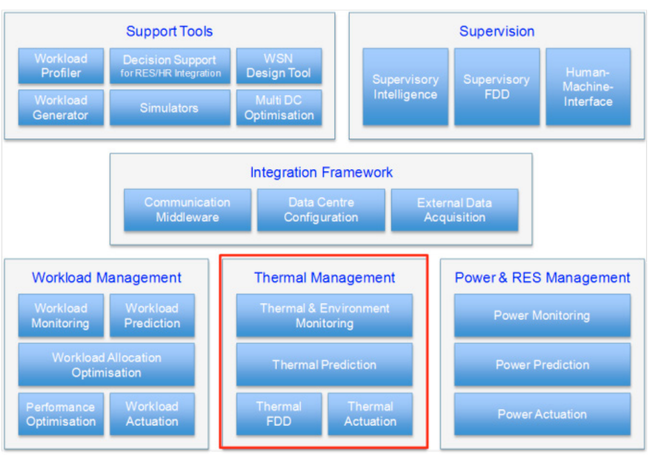


Fig. 1. GENiC system component architecture.

In a distributed setting, a middleware component has been developed for the integration and the exchange of information between workload, thermal, power and other GENiC groups. In view of Fig. 1, the supportive tools group contains: an IT workload profiler generator component for generating traces of virtual machines for optional use with external DC simulators; a decision support RES/HR component aiming the selection of right DC green energy available solutions depending on budget and DC location; a wireless sensor network which is used to record various DC room measurements (e.g. temperatures, airflows, etc.); and a multiple DC optimisation component tool which is used to allocate IT workloads between different DCs. The supervision group provides additional simulation and supervisory control capabilities. In particular, the supervisory intelligence component constitutes a high level DC management optimization module. This component recommends optimal policies to workload and power groups, as well as DC room info-structure operational envelops and constraints to the thermal management components. The fault detection and diagnosis (FDD) component provides system level alarm management. Finally, at the operator's front end, a HMI service component enables the DC operator to monitor and manage system optimization.

The focus of this work is on temperature control which is contained within thermal management group highlighted in the architectural diagram in Fig. 1.

### *2.2 Thermal management components*

The thermal management group consist of four main subsystems as shown in Fig. 1:

- Thermal & Environment monitoring – provides temperature monitoring for DC room for front and back of the racks as well as inlet and outlet for HVAC system. Due to limited space this component is not described herein.
- Thermal Prediction (TP) – component responsible for computing next thermal control oriented dynamical models for HVAC system control based on monitoring data received from monitoring components.
- Thermal Actuation (TAC) – component that derives optimal control HVAC temperature set points and remotely actuate the HVAC system.
- Thermal FDD – fault detection and diagnosis used to aggregate alarms from controlled devices and provide decision support for alarm handling. Thermal FDD is not described in detail this paper.

The TP and TAC components are implementing system identification and control algorithms in real time environment. In view TP and TAC, the design process of DC room temperature profiles regulation control systems via actuation of available cooling equipment is shown in Fig. 2.

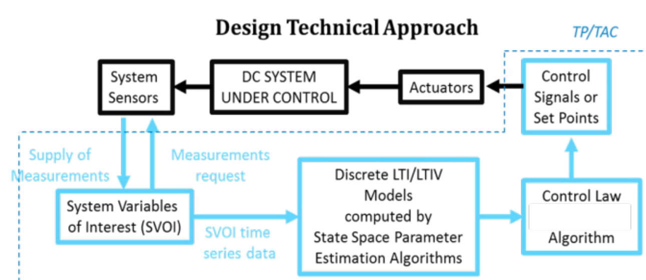


Fig. 2. DC temperature control process.

As Fig. 2 illustrates, the temperature control process consists of the following sequential steps.

1. Determine the DC System Variables of Interest (SVOI) in DC that will form the model (model states) and request these SVOI online in fixed time sampling periods (5 minutes currently adopted in this work).