Self-healing Behaviour in Smart Grids

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***Abstract*—Smart grids are considered to be the future of power systems. Solutions from the domain of Information and Communication Technology(ICT) are increasingly being introduced to better integrate a wide range of distributed energy resources. The objective is to make smart grid systems robust and highly dependable. We present our approach to make a self-healing smart grid node. A complete and consistent set of requirements defines the desired behaviour of the system. This desired system behaviour is continuously monitored to detect, identify and classify the fault. Since self-healing system must also be able to heal itself, it must be aware of the faults, nature of faults to perform recovery actions.**

I. INTRODUCTION

Environmental, social and economic drivers accelerate the research on the future of energy systems. According to the IEEE smart grid association [1], *the "smart grid" has come to describe a next-generation electrical power system that is typified by the increased use of communications and information technology in the generation, delivery and consumption of electrical energy*. Fang et al.[2] have studied and compared the smart grids with the existing power grids: Future grids will have features such as digital (usage of ICT technology for intelligent control over the power grid infrastructure), two-way communication (information exchange between the various entities in the power network), distributed generation(generation of energy from many sources to improve energy supply), self-monitoring, self-healing, adaptive (for instance, dynamic prices based on demand and supply) and islanding (a smart grid node continues to sustain itself with energy supply even when it is disconnected from the power grid) as opposed to the existing power grids which uses electrochemical technology, have one-way communication, centralized energy generators and provide limited choice to the customer.

The vision for smart grids can be achieved with close coupling of ICT into the energy domain. In order to re-shape the future of energy grids, stability and reliability are two of the critical features that future smart grids must exhibit. For these reasons, we seek ICT solutions for self-healing smart grids.

Self-Healing systems have been compared with the existing approaches, such as de Lemos [3] has highlighted the differences and similarities between self-healing and fault tolerance. He emphasized that there is no clear understanding of the term *self-healing*. As mentioned there, that there are self-healing strategies for the software domain but for hardware domain they are still not clear. Smart grids will be combination of intelligent software controlling the energy infrastructure. With more software control on the energy infrastructure, smart grids are not only fault-tolerant, but are also envisioned to be self-healing. Hence the proactive recovery with minimum or no loss of service is the aim in future smart grids.

In this paper, we present our approach to self-healing behaviour in smart grids. Identification of faults as the *trigger* that causes the deviation from desired behavior. We combine workarounds and adaptation [4] approaches for the recovery process.

II. RELATED WORK

Self-healing properties have often been described as one of the core properties of autonomic computing. Salehie and Tehvildari [5] have highlighted the focus of industry and academia in various areas of autonomic computing. They have also described the relationship of self-healing with the quality factors such as availability, survivability, reliability and maintainability. This helps in better understanding of the term "self-healing" in smart grids domain. Ghosh et al. [6] have defined and explained the principles of self-healing systems in the IT domain as *the property that enables a system to perceive that it is not operating correctly and without (or with) human intervention, make the necessary adjustments to restore itself to normalcy.* Rodosek et al. [7] have defined self-healing systems and elaborated the clear distinction of self-healing systems with fault-tolerant systems and other self-* systems especially self-stabilizing, self-optimizing systems. Koopman [8] has listed out the elements of self-healing problem space as fault model, system response, system completeness and design context.

Garlan et al. [10] have proposed a model-based adaptation for self-healing system. They have introduced the use of externalized adaptation approach.The run time behavior of the system is observed by the monitoring component, the monitored vales are then compared with the architectural model which triggers constraint evaluation. Thus, it is determined when the system is operating within an acceptable range. A violation of the constraints triggers the repair actions, which adapts the architecture. These architectural changes are then propagated to the running system.

Taking forward the idea of Koopman [8] , we will study self-healing from the design context aspect by defining the behavior models. It is important that the formal specification of such systems be done in order to make verification of self-healing behavior possible. In our study, we take the formal approach of studying the behavior of the self-healing smart grids.

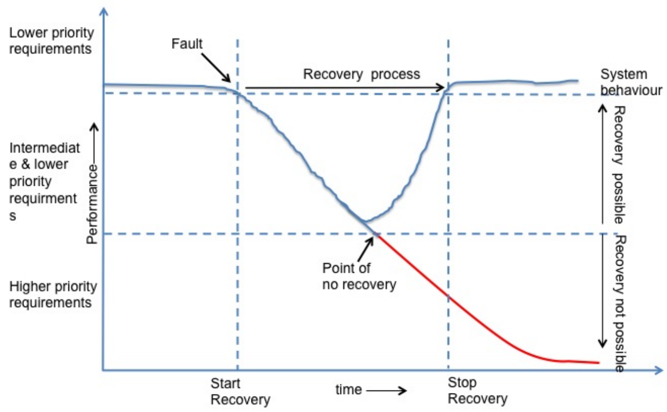

Fig. 1. Behavior of the system dependent on the conformance to the requirements

III. Research Objectives

In our study we consider the concept of a self-healing system as *the system that can make all the necessary recovery steps by itself to restore its distributed behavior to a specified mode of operation* [7]. We will focus on the design level aspects of a smart grid system to monitor its performance, detected and identify the faults encountered and apply the pre-defined recovery strategies to bring system performance back to a specified mode of operation. The predefined fault profiles and the corresponding recovery actions are fed into the system. The recovery actions include workarounds, re-organization of the system and use of redundant components. Therefore, the thesis has the following objectives:

Objective 1: System definition.
Objective 2: Dealing with faults.
Objective 3: Recovery procedures.

IV. Research Methodology

To find a solution to **Objective 1** definition of an energy system is required.

1.1 Requirement elicitation: A complete set of requirements will provide a basis for the definition of the desired behaviour. These requirements are then prioritized as the higher, intermediate and lower level requirements. *higher level* requirements must be followed by the system at all times, while *intermediate and lower level* requirements are those that could be ignored or compromised for certain time duration. Based on the requirement prioritization we classify the system behaviour on a higher level as: desired, deviated and undesired behaviour. Within each class of requirement several gradations are feasible.

1.2 Environmental Constraints: The interfaces to the environment in which the system will operate will be defined. The behaviour of the system with the external components must be known. Therefore, interface definitions and interaction with the external components must be included in the requirement elicitation.

The evaluated constraints (requirements) will be implemented as rules following conditional statements (IF THEN). Furthermore, the creation and ongoing adaptation of rule parametrization based e.g. on historical behavior allows for a higher flexibility regarding the priority categories.

In **Objective 2** the focus is on the detection, identification and classification of faults.

2.1 Detection and identification of faults: Faults are detected and identified on the kind of behaviour system exhibits. this involves an analysis of the deviation from a desired behaviour to deviated behaviour state. In other words, fault can be detected when the rule for the desired behaviour is not triggered, which means that the condition has not met. Hence, it can be inferred that one of the participating components involved in that requirement/constraint are faulty.

2.2 Classification of faults and scope of recovery: Classification of faults plays a crucial role for the recovery of the system. The criteria for the classification of faults depends on the rule (requirement) that was violated. If a higher priority requirement is violated then the fault can bring a complete disruption to system. In other words, if higher priority requirements are violated then system goes to an undesired state, which means that it has reached to point of no recovery.

In **Objective 3** the focus is on the recovery procedures that must be followed to bring back the system to its specified operation level.

3.1 Passive recovery: We let the system stay in the deviated state till the faulty component is being repaired. This means that the system enters into degraded state, and under performs for the certain duration. The system continues to remain in deviated behaviour. This approach helps when a fault is induced due to the external (environmental) factors.

3.2 Active recovery: This means the deliberate actions performed to bring back the system to its desired behaviour level. In case of hardware faults, this is physically replacing the faulty device with the new one. In case of software faults, the component is overwritten with the redundant component.

V. Future work

Approches discussed so far will be tested in smart energy living lab at fortiss.

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