INTRODUCING THE CONCEPT OF TECHNICAL DEBT TO SMART GRIDS: A SYSTEM ENGINEERING PERSPECTIVE

Johann SCHÜTZ
OFFIS – Institute of Information Technology – Germany
Johann.Schuetz@OFFIS.de

Mathias USLAR
OFFIS – Institute of Information Technology – Germany
Mathias.Uslar@OFFIS.de

ABSTRACT

With the growth of the system-term from closed technical systems to complex, open and highly interconnected socio-technical system-of-systems, as is the smart grid, new challenges emerged. One of them is the huge and still accumulating amount of technical debt and the associated constant loss of quality. Technical debt is a well-known and commonplace problem in the domain of systems engineering. It is unavoidable and grows over time as the system evolves. If not actively managed, it compromises the internal and the associated external quality of a system. As a result, if multiple systems with mutual interdependencies among each other perform bad (e. g. due to poor internal quality) they affect the smart grid quality attributes as a whole.

Currently, there is no research on technical debt within smart grids, although it is an inevitable omnipresent problem in every system. This paper shows the absence of technical debt research in the domain of smart grid and argues why there is a need for change.

INTRODUCTION

Enforced by the growing decentralisation of the power grid the necessity of an intelligent and efficient monitoring and coordination between all actors along the energy conversion chain grows.

In order to meet those real time requirements and to leverage mutual synergies all technical and non-technical actors, such as transmission system operators (TSO), distribution system operators (DSO) and prosumers, have to open and interconnect their heterogeneous systems [2]. For this purpose, these systems need to be interoperable at least on a technical, informational and organizational level [4][10]. Nevertheless, opening and interconnecting a system blurs its own boundaries. The hitherto clear defined boundaries, stakeholders and areas of responsibility become a part of a complex socio-technical system-of-systems with strong interdependencies among the constituent systems. Due to the accompanying complex inter-organisational and socio-technical interdependencies, the wicked [17] characteristics of the systems engineering discipline becomes more apparent. The resulting, inevitable and continuous evolution of each constituent system creates new challenges for the system-of-systems, as is the smart grid, as a whole [12]. One of them is the huge and still accumulating amount of technical debt and the associated constant loss of quality.

The remainder of the paper is organized as follows. First, the terms wicked problem and technical debt are introduced. Section 2 then presents the current state of research. Section 3 presents the related problem and cause-effect relationships. Afterwards an example from practice is given in section 4. Finally a conclusion is drawn in section 5 and the open and still to be worked on research questions are presented in section 6.

Wicked Problem

The engineering of complex systems underlies the wicked problem complexity. These problems are impossible to master. The solution to a wicked problem depends on how the problem is framed and vice versa; moreover a solution to a problem is connected to other problems with no determinable stopping rule. Therefore, problems with wicked characteristics can not be solved correct or wrong, just good or bad. Further, even if a solution is considered good, the assessment of the situation may change as new stakeholders with new or different points of view emerge. [17]

Thus, we learn more about how a system should not be build than how a system should be build [5]. This leads to continuous changing requirements and subsequently, to a permanent evolution of all systems without a determinable stopping point.

Technical debt

Technical debt, a metaphor introduced by Ward Cunningham [16], basically refers to a technological gap between the is- and should state of a system as a stakeholder friendly analogy. Cunningham originally used it to describe the learning curve during the software development-process and the necessity of architecture or design revisions as new knowledge and experience arise. He stated that immature code may work fine, but excess quantities will make the program unmasterable and finally lead to an inflexible product. The core message of this metaphor is that a small amount of debt can have short-term benefits, but if you do not pay off the debt, it will eventually lead in the long-term into a not redeemable disaster. [16]

Back then, Cunningham referred to technical debt in software systems and the risk of its accumulation. But, once technical debt has occurred in cross-organizational socio-technical system-of-systems, the elimination or repayment is not as simple.

STATUS QUO

Technical debt is becoming an increasingly important topic in both industry and science. This is also reflected in the increasing research resp. publications, which have more than tripled within the past eight years as **Fig. 1** shows. The chart is based on a Google Scholar search results with „technical debt“ in its title.

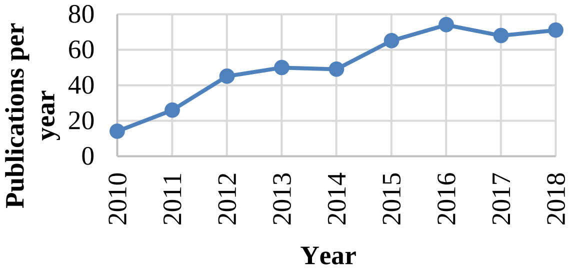

Fig. 1 Number of publications per year with technical debt as the main topic

With the increasing complexity of modern systems, technical debt is also becoming an increasingly critical problem. So it is becoming also increasingly important. Especially, in the discipline of software development and systems engineering itself. But, the smart grid as a complex socio-technical and even critical system-of-system with an unprecedented scale in multiple dimensions [9] lacks that research.

An initial full text literature research with the the search terms “smart grid” and “technical debt” in multiple scientific databases (Informs, ScienceDirect, SpringerLink, EconBiz, Orbis+, AIS, Emerald, IEEE, Elsevier, ACM, Scopus and Google Scholar) resulted in no relevant matches. Only two articles [1][7] which mention technical debt as a crucial issue in smart grids in the future, but do not investigate the topic further. This also applies to other emergent domains, such as smart cities with almost identical problems. The problem was identified, but has not been investigated either [14].

The lack of technical debt research in the domain of smart grids is most likely explained due to the fact that technical debt is a phenomenon which appears on the macro level of the constituent systems and, therefore, is considered as an internal quality issue. For this reason, the current technical debt research focuses on an economical cost-benefit for an internal optimization from a managerial point of view [18]. However, related topics, such as the quality of service or resilient architectures, are being investigated. However, these approaches do not solve the problem where they arise. They essentially examine requirements and approaches to counteract the effects of technical debt without solving the problem itself.

THE NATURE OF THE PROBLEM

The emerging problem of accumulating technical debt is amplified by the natural continuous evolution of each socio-technical system.

Continuous Evolution as an amplifier

In order to achieve higher capabilities, the constituent systems of a smart grid need strong interdependencies among each other. By facilitating mutual synergies, these systems are able to achieve an emergent behaviour and new capabilities beyond the sum of its parts [12]. To leverage and harvest such synergy effects, first the heterogeneous systems must be interconnected. From a system-of-systems level point of view and in accordance to the OSI model (Open Systems Interconnection model) these systems need a common understanding or agreement on standardized communication protocols on multiple layers first as **Fig. 2** shows.

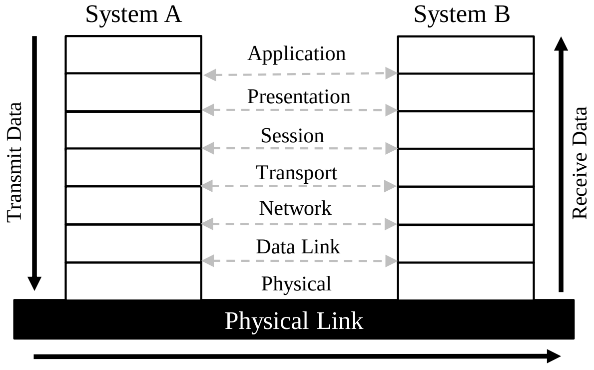

Fig. 2 The seven Layers of the OSI model

However, such an agreement affects the technical, informational and organizational level of all participating systems and have to be implemented in each one of them. These constituent systems are (in the most cases) self-sufficient systems with own general conditions, stakeholder and profit-oriented goals. They even can participate on multiple system-of-systems. This leads to the fact that the individual interests take precedence over the interests of the whole and, in addition, also to a further leverage of the previously introduced wicked characteristics. Thus, each system owner has his individual starting point, requirements, understanding of the problem and therefore preferred solution.

Although it is the most obvious solution to agree on already established and accepted standards to address those problems. It is impossible for a generalized standard to meet all of the individual requirements of all stakeholders. Further, even standards are subject of the wicked problem. They only mitigate but do not solve the wicked problem. For instance, the Common Information Model (CIM) as an essential part of the IEC 61970 and IEC 61968 which defines the standard for the communication between energy management systems. This standard has not only already outgrowing its original purpose, it is still evolving [11]. Although, the application and scope is considered as the state-of-the-art between the TSO and the DSO information exchange [11], it is attempted to harmonize it with further (at the moment) not compatible standards such the IEC 61850 for intelligent electronic devices at electrical substations [15].

The constantly changing environment, combined with a multitude of additional internal and external influencing factors, enforces a continuous adaptation to new requirements and amplifies the accumulation of technical debt in every constituent system.

Accumulation of technical debt

Especially earlier technical devices (legacy systems) were never designed to be interoperable and therefore have to be replaced or in any case upgraded to an intelligent and interoperable device. This includes hardware as well as software modifications. For obvious reasons, a system cannot be replaced whenever it can no longer meet the current requirements. But, a modification on a system, especially on software, cannot be done without an influence on the quality. Every necessary modification leads to an economical trade-off decision between re-engineering the system to avoid or at least to minimize the quality loss or a “quick and dirty”-solution to reduce further re-engineering costs. Those trade-off-decisions are well-known and commonplace business decisions in the domain of systems engineering. The problem is that, traditional technical debt-management considers technical debt as a closed phenomenon and therefore handles it as an isolated short- or long-term trade-off-decision. Even if technical debt is actively managed at all, it is customary to optimise it based on selfish internal cost-benefit assessments.

Cause and Effect Relationship

Following the metaphor of technical debt, a small amount of (technical) debt may be reasonable [16]. Especially since it is unavoidable. Nevertheless, due to the continuing evolution the accumulation of technical debt over time is inevitable.

In terms of system quality, it means, every trade-off-decision without considering the existing interdependencies and against the more costly quality causes an additional quality atrophy. Although, it is basically considered as an internal quality attribute, the internal quality of a system is linked to its external quality [6][8]. In reference to W. Cunningham [16] this may work fine and is hardly noticeable, but excess quantities eventually lead to an unmasterable program. While Cunningham referred to a software system and the possible financial risks of technical debt, it is a more severe problem as a part of a critical system-of-systems. Thus, the possible consequences are not limited to an internal financial risk. As a part of a system-of-systems, it compromises the quality attributes of the smart grid as a whole. Since the quality of a system is composed of multiple characteristics (e.g. SQuaRE of the ISO/IEC 25010-standard for „Systems and software engineering -- Systems and software Quality Requirements and Evaluation (SQuaRE) -- System and software quality models“ [6]) and the different types of technical debt are able to affect all of them [18].

The degree of severity depends on the role within the smart grid from an architectural point of view. It grows with the number of dependencies to other systems. Since the DSO is gaining an increasingly crucial role in the transformation of the energy system, he is one of the most affected. In order to maintain the energy grid stability, the DSO will have to coordinate between a large number of volatile energy resources. For this purpose, each of the constituent systems must be safe and reliable. A single failing system can turn existing synergies to dysergies and lead from failure propagation to a cascading failure and in the worst-case scenario up to a shut down of the smart grid. Hence, if one constituent system changes its behaviour or worst performs poorly due to a cumulative quality loss over time, it will affect the interacting systems [13] and, therefore, the smart grid as a whole.

EXAMPLE

The German so called Verteilernetzstudie “Moderne Verteilernetze für Deutschland” [3] serves as a summerized example. The title can be translated in: Distribution Grid Study „Modern Distribution Grids for Germany“. In 2014, this study investigated the extension requirements of the German distribution grid for the integration of renewable energy sources. The aim is to increase the share of renewable energies (in gross electricity consumption) from at that time 23% to over 50% by 2032 and to 80% by 2050. Therefore, the main objective of the study was to quantify the extension requirements for the German distribution networks. Further, which strategies using intelligent network technologies can reduce the necessary extension and the associated integration costs? [3]

One of the problems is that the Distribution Network Operator (DNO) has to plan under high uncertainties. The continuous changing network capacity requirements are not equally distributed over time. Resulting in that the installation of additional renewable energy systems is not known in advance and can change in the short term. In order to address this problem, the basic planning was based on the projected years 2017 and 2022 and the year 2032. A so-called projected year defines a period of time up to which the necessary grid extension is simulated. The development path of renewable energy plants is known up to this point. The study covers the years 2017 and 2022. For a first reference evaluation, it was initially assumed that the DNO would stepwise complete all its investments for the corresponding projected years. Firstly, all the investments required fulfilling his tasks in 2017, then he completes further network extension measures to fulfil his transport tasks in 2022, and finally a third time to meet the requirements for 2032. But, within the scope of a sensitivity analysis, it was examined whether there is potential for cost savings in network extensions if the network extension is optimized directly to the requirements in 2032. A direct comparison of the new results with the initial reference calculation showed that the grid extension requirements for the low-voltage level network could be reduced by 4.5 %, the medium-voltage level network by 16 % and the high-voltage level network by 25 %. **Fig. 3** shows an example of the study on the savings in extension in the medium-voltage level network. [3]

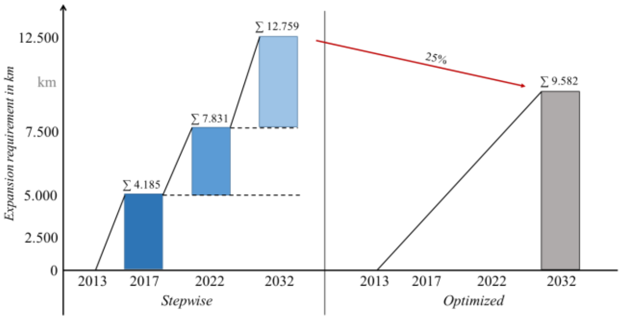

Fig. 3 Reduced network extension requirements [3]

From the perspective of systems engineering this is linked to the stepwise approach. During the implementation of each step, technical and organizational decisions are commonly optimized on the basis of the current requirements, so that each step seeks its own optimum. However, the local optima often do not fully comply with the global optimum. For this reason, in order to align the decisions previously made with the global optimum, additional efforts have to be made after each step. The mismatch between the global optimum and the local optima and the associated additional costs can be regarded as technical debt, which could be avoided. In addition, it should also be considered that the amount of inflicted technical debt is directly correlated with the quality of the forecasts. As more the forecast of the projection points and the associated migration paths drifts apart from reality, as more the local optima differs from the global optimum. Thus, the technical debt and the required corrective countermeasures accumulates over all steps.

Furthermore, the study showed, among many others results, e.g. that the usage of innovative generation management concepts in network planning, unnecessary network expansion can be avoided. Thus, intelligent components such as the Voltage Regulating Distribution Transformer (VRDT) have only to be installed in the networks that, despite the generation management, still have a remaining extension requirement. Within the study, this means:

- Instead of over 45.000 VRDTs, only about 10.000 VRDTs will have to be installed by 2032.
- The reduction in investment costs of around 60 % evenly across all voltage networks levels.
- The average annual costs are reduced by approx. 20 %.

For that very reason, with the potential impact in mind the technical debt caused by early decisions should be considered both politically by the government and organizationally by the energy suppliers.

CONCLUSION

The ongoing transition from a centralized to a decentralized power grid accelerates the accumulation of technical debt. Legacy systems are being upgraded for functionality they were never designed for. New systems are being developed for the first time. Immature standards, policies and processes, which have yet to be matured. A wide variety of amplifier, which contribute to this through their necessary maturation.

The cause-effect relationship of technical debt in socio-technical systems and beyond in system-of-systems should be considered in the planning and development of smart grid ecosystems. Otherwise, the consequences and additional costs of supposed trivialities are unpredictable.

While the understanding of the system-term or more its boundaries within the discipline of systems engineering evolved over time, the understanding of technical debt has not. It is primarily still considered as an internal quality attribute. Technical debt should be understood as a potentially critical cross-system factor that can dilapidate the smart grid as a whole. In this context, as a part of a critical system-of-systems, technical debt-management should consider the cross-system interdependencies, instead of a mere internal cost-benefit optimization.

FUTURE RESEARCH

Not all types of technical debt affects all quality attributes. To understand the cause-effect relationship between the different types of technical debt and the different quality dimensions in detail, further work is necessary. Since technical debt cannot be avoided, at least the management can be supported. For this purpose, a holistic quality model is required, that considers the possible cross-organizational impact of the different technical debt types. In addition, the gradual and imperceptible change in the behaviour of the constituent systems as well as of the smart grid may not even be actively perceived until they fail at some point. However, changes in system behaviour can be observed and monitored in the long term, so that possible negative changes in constituent systems can be identified at an early stage. In order to be able to act preventively, suitable Key Performance Indicators (KPI) must be developed and implemented.

REFERENCES

[1] C. Fernández-Sánchez, J. Garbajosa, A. Yagüe, J. Perez, 2017, “Identification and analysis of the

elements required to manage technical debt by means of a systematic mapping study", Journal of Systems and Software, Volume 124, 22-38.

[2] CENELEC-ETSI Smart Grid Coordination Group, 2012, "CEN-CENELEC-ETSI Smart Grid Coordination Group – Smart Grid Reference Architecture", CEN/CENELEC/ ETSI.

[3] E-Bridge; IAEW; OFFIS (2014): Moderne Verteilernetze für Deutschland (Verteilernetzstudie). Studie im Auftrag des Bundesministeriums für Wirtschaft und Energie (BMWi) (Forschungsprojekt Nr. 44/12). Online: http://www.bmwi.de/BMWi/Redaktion/PDF/Publikationen/Studien/verteilernetzstudie,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf.

[4] GridWise Architecture Council (GWAC), 2008, "GridWise Interoperability Context-Setting Framework (March 2008)", GridWise Architecture Council, online: www.gridwiseac.org/pdfs/.

[5] I. Sommerville, 2010, "Software Engineering (10th ed.)", Pearson, Global Edition, USA.

[6] ISO/IEC, 2010, "ISO/IEC 25010 - Systems and software engineering - Systems and software Quality Requirements and Evaluation (SQuaRE) - System and software quality models".

[7] J. Yli-Huumo, K. Smolander, 2017, "Changes and Challenges of technical debt and Its Management During Ongoing Digital Transformation", Proceedings of the XP2017 Scientific Workshops, 2:1-2:4.

[8] L. Lavazza, S. Morasca, D. Tosi, 2018, "Technical debt as an external software attribute", Proceedings of the 2018 International Conference on Technical Debt (TechDebt '18), ACM, New York, NY, USA, 21-30.

[9] M. Uslar, 2015, "Energy Informatics: Definition, State-of-the-Art and New Horizons", Symposium Communications for Energy Systems, ComForEn 2015, vol. 6, 15-26.

[10] M. Uslar, D. Engel, 2015, "Towards Generic Domain Reference Designation: How to learn from smart grid Interoperability". D-A-Ch Energieinformatik, vol. 1, 1-6.

[11] M. Uslar, M. Specht, S. Rohjans J. Trefke, J. M. Gonzalez, 2012, "The Common Information Model CIM: IEC 61968/61970 and 62325 - A practical introduction to the CIM", Springer, Berlin.

[12] Office of the Deputy Under Secretary of Defense for Acquisition and Technology, Systems and Software Engineering. Systems Engineering Guide for Systems of Systems, Version 1.0. Washington, DC: ODUSD (A&T) SSE, 2008.

[13] S. Alter, 2018, "System Interaction Theory: Describing Interactions between Work Systems. Communications of the Association for Information Systems", Communications of the Association for Information Systems, vol. 42, article 9.

[14] S. Tousley and S. Rhee, 2018, "Smart and Secure Cities and Communities," 2018 IEEE International Science of Smart City Operations and Platforms Engineering in Partnership with Global City Teams Challenge (SCOPE-GCTC), 7-11.

[15] TDX-ASSIST, 2018, "Coordination of Transmission and Distribution data eXchanges for renewables integration in the European marketplace through Advanced, Scalable and Secure ICT Systems and Tools (TDX-ASSIST)", TDX-ASSIST, online: http://www.tdx-assist.eu/.

[16] W. Cunningham, 1992, "The WyCash portfolio management system", In Addendum to the proceedings on Object-oriented programming systems, languages, and applications (Addendum) (OOPSLA '92), Jerry L. Archibald and Mark C. Wilkes (Eds.). ACM, New York, NY, USA, 29-30.

[17] W. Rittel, J. Webber, 1973, "Dilemmas in a General Theory of Planning", Policy Science, vol. 4(2), 155-169.

[18] Z. Li, P. Avgeriou, P. Liang, 2015, "A systematic mapping study on technical debt and its management", Journal of Systems and Software, Volume 101, 193-220.