UNIVERSITI PUTRA MALAYSIA

THEORY OF INVENTIVE PROBLEM SOLVING BASED SECTOR SPECIFIC GUIDANCE FOR ELECTRICAL ENGINEERS TO SEEK INNOVATIVE SOLUTIONS SYSTEMATICALLY

MUHAMMAD MANSOOR

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DOCTOR OF PHILOSOPHY
UNIVERSITI PUTRA MALAYSIA

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By

MUHAMMAD MANSOOR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

June 2013

-.-.-.-.-.-.-.-

I dedicate this thesis to all those who were part of my life, who are part of my life and who will be part of my life, whether for good or bad. Because all of them make me learn and be who I was, who I am and who I shall be.

-.-.-.-.-.-.-.-

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
in fulfillment of the requirement for the degree of Doctor of Philosophy

THEORY OF INVENTIVE PROBLEM SOLVING BASED SECTOR SPECIFIC GUIDANCE FOR ELECTRICAL ENGINEERS TO SEEK INNOVATIVE SOLUTIONS SYSTEMATICALLY

By

MUHAMMAD MANSOOR

June 2013

Chair: Professor Ir Norman Mariun, PhD

Faculty: Engineering

Complexity of engineering systems is growing with integration of multiple technologies as one system. It is becoming hard for engineers to address problems in a system, which needs expertise in multiple technological domains. To cater this ever growing complexity, systematic guidance is a worthy assistance. To help engineers generate focused ideas, determine probable solution directions and foresee future developments in a sector, while providing systematic guidance is a valuable support.

With the aim of supporting engineers to meet today's challenges, this research used capabilities of TRIZ for development of sector specific guidance. The generated guidance is worked to be optimized for sub-domains of a major field. To reduce this complexity and facilitate engineers, TRIZ do offer a strong set of tools and methods. The approach of working out sector specific guidance for smaller sectors will open a window for new ideas, to seek future transitions of engineering systems in specific

sector. It will also reduce need of a TRIZ expert in dealing a problem, while looking for TRIZ based solution guidance.

Taking engineering solution design stages into consideration, this research aims for guiding engineers at conceptual design stage of solution hunting. A strong conceptual design will result in less design iterations, hence reducing time and cost of solution hunting process. With this aim, the research seeks to set a direction and methodology for 'how to generate sector specific guidance framework'. The research successfully met all objectives to meet the aim of this research. For this purpose, the research worked out three cases from different sub-domains of electrical engineering. The chosen cases are significant topics in electrical power engineering now a day, i.e. sustainable energy development, asset management and dynamic voltage restorer (DVR) devices. To validate proposed methodology and resulted guidance framework, it executes an example of a real problem with help of developed guidance framework. Effective results are achieved by application of developed guidance framework, which validates research approach and methodology. Successful results achieved for development of systematic guidance are presented for all three cases.

Abstract tesis yang dikemukakan kepada Senate Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Flasafa

TOERI PENYELESAIAN MASALAH INVENTIF BERASASKAN BIMBINGAN SEKTOR KHUSUS UNTUK JURUTERA ELEKTRIK BAGI MENCARI PENYELESAIAN INOVATIF SECARA SISTEMATIK

Oleh

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Fakulti: Kejuruteraan

Sistem kejuruteraan semakin kompleks dengan terjadinya integrasi pelbagai teknologi dalam satu sistem. Ia menjadikan sukar bagi jurutera untuk menangani masalah dalam sistem, yang memerlukan kepakaran dalam pelbagai domain teknologi. Untuk menangani kekompleksan yang kian meningkat ini , panduan yang sistematik dapat memberikan bantuan yang berguna. Di dalam menyediakan panduan sistematik, ia adalah sokongan yang sangat berharga untuk membantu jurutera menjana idea yang fokus, menentukan arah kebarangkalian penyelesaian yang ada dan meramalkan perkembangan masa depan dalam beberapa sektor.

Dengan matlamat menyokong jurutera untuk menghadapi cabaran hari ini, kajian ini menggunakan keupayaan TRIZ bagi membangunkan panduan untuk sektor spesifik. Panduan yang terjana dioptimakan untuk sub-domain dalam bidang utama. Untuk mengurangkan kekompleksan ini dan memudahkan jurutera, TRIZ menawarkan teknik dan kaedah yang kukuh. Pendekatan dengan pelaksanaan panduan spesifik sektor bagi

sektor kecil akan membuka kepada idea-idea baru, untuk mencari transisi masa depan dalam sistem kejuruteraan pada sektor yang spesifik. Ia juga akan mengurangkan keperluan pakar TRIZ dalam menangani masalah, sementara mencari panduan penyelesaian berasaskan TRIZ .

Dengan mengambilkira peringkat reka bentuk penyelesaian kejuruteraan, penyelidikan ini bertujuan untuk membimbing jurutera pada peringkat konsep reka bentuk untuk memburu penyelesaian. Satu konsep reka bentuk yang kuat akan dapat mengurangkan lelaran reka bentuk, dengan itu mengurangkan masa dan kos dalam proses mencari penyelesaian. Berdasarkan sasaran ini, kajian ini bertujuan untuk menetapkan hala tuju dan kaedah untuk ‘ bagaimana untuk menjana rangka kerja panduan untuk sektor spesifik’. Bagi tujuan ini, penyelidikan ini menjalankan tiga kes kajian daripada sub-domain yang berbeza-beza dalam kejuruteraan elektrik. Kes-kes yang terpilih adalah topik-topik yang signifikan dalam kejuruteraan kuasa elektrik pada masa kini, iaitu pembangunan tenaga yang mampan, pengurusan aset dan peranti pemulih dinamik voltan (DVR). Untuk mengesahkan kaedah yang dicadangkan dan kerangka kerja panduan yang terhasil, ia melaksanakan satu contoh masalah sebenar dengan bantuan rangka kerja panduan yang dibangunkan. Hasil keputusan yang berkesan dapat dicapai oleh applikasi rangka kerja panduan yang dibangunkan, dimana ia mengesahkan pendekatan kajian dan metodologi. Hasil keputusan yang sangat berjaya yang telah dicapai bagi membangunkan panduan sistematik telah terbentang dalam ketiga-tiga kes kajian.

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Muhammad Mansoor

26th Feb 2013

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TABLE OF CONTENTS

			Page
ABSTRACT			iii
ABSTRAK			v
ACKNOWLEDGEMENTS			vii
APPROVAL			x
DECLARATION			xii
LIST OF TABLES			xvi
LIST OF FIGURES			xviii
LIST OF ABBREVIATIONS			xx
CHAPTER			
1	**INTRODUCTION**		1
	1.1	Background	1
	1.2	Conventional Solution Techniques and Current Needs	2
	1.3	Theory of Inventive Problem Solving (TRIZ)	4
	1.4	Problem Statement	5
	1.5	Research Objectives	7
	1.6	Research Methodology	8
		1.6.1 Methodology Description	8
		1.6.2 Method of Analysis	9
		1.6.3 Verification of Methodology	9
	1.7	Benefits, Scope and Limitations	10
		1.7.1 Benefits	10
		1.7.2 Scope and Limitations	11
	1.8	Thesis Organization	12
2	**LITERATURE REVIEW**		14
	2.1	Introduction	14
	2.2	Engineering Systems and Engineering Solution Design	14
		2.2.1 Technology Development and Engineering Systems Complexity	14
		2.2.2 Engineering Solutions, Engineering Design and Design Stages	16
		2.2.3 Established Engineering Problem Solving Techniques	18
	2.3	Knowledge Engineering and Knowledge Management Approach	22
		2.3.1 Knowledge, Knowledge Based Systems and Knowledge Engineering	22
		2.3.2 What is Innovation and Need of Innovation/creativity in Engineering Solutions?	24
		2.3.3 Established Creativity/Innovation Methodologies	26
	2.4	Understanding TRIZ	30

2.4.1 Introduction of TRIZ 30
2.4.2 TRIZ Methods and Toolset 33
2.4.3 Established Engineering Problem Solving Methodologies and TRIZ 38
2.4.4 Established Creativity Methodologies and TRIZ 39
2.4.5 Advantages of TRIZ 39
2.4.6 Taking the "TRIZ" Approach 43
2.5 Three Selected Case Studies 47
2.5.1 Case Study 1: Dynamic Voltage Restorer 48
2.5.2 Case Study 2: Sustainable Energy Development 49
2.5.3 Case Study 3: Asset Management in Smart Grid Era 51

3 CASE 1: DEVELOPMENT OF GUIDANCE CHART FOR DYNAMIC VOLTAGE RESTORER 53
3.1 Introduction 53
3.2 Research Approach and Methodology 55
3.3 Analysis and Results 57
3.3.1 Problem Definition – DVR Protection for Voltage Sag 57
3.3.2 Resources 59
3.3.3 Ideal Final Result 59
3.3.4 DVR's standing along TRIZ Trends of Engineering System Evolution 60
3.3.5 DVR's Standing along TRIZ S-Curves Development Life Cycle 62
3.3.6 DVR's Analysis by Contradiction Matrix Mapping 65
3.4 Results Summary and Discussion 67
3.5 Conclusions 71

4 CASE 2: DEVELOPMENT OF GUIDANCE CHART FOR SUSTAINABLE ENERGY DEVELOPMENTS 72
4.1 Introduction and Literature Review 72
4.2 Research Methodology 74
4.3 Data Acquisition, Analysis and Results 76
4.3.1 Sustainable Development and TRIZ 76
4.3.2 Sustainable Energy and Future Approach 79
4.3.2.1 TRIZ and Eco-efficiency Principles 80
4.3.2.2 TRIZ and Energy Principles 83
4.3.2.3 TRIZ and Future Energy Scenarios 87
4.4 Results Summary and Discussion 89
4.5 Conclusions 93

5 CASE 3: DEVELOPMENT OF GUIDANCE CHART FOR ASSET MANAGEMENT IN SMART GRID ERA 94
5.1 Introduction 94
5.2 Literature Review 96

5.2.1 TRIZ: An Emerging Tool 96
5.2.2 Asset Management 96
5.2.3 Smart Grid 97
5.2.3.1 Smart Grid and Asset Management 98
5.3 Research Approach and Methodology 100
5.4 Analysis and Results 102
5.4.1 Smart Grid – Asset Management KPIs and TRIZ Parameters 103
5.4.2 TRIZ-TESE Analysis 105
5.4.3 TRIZ-S-Curve Analysis/Recommendations 105
5.4.4 TRIZ Inventive Principles 108
5.5 Results Summary and Discussion 110
5.6 Conclusions 113

6 DEVELOPMENT OF A SOLUTION FOR DVR RESPONSE TIME TO VOLTAGE SAG USING DEVELOPED CONCEPTUAL FRAMEWORK 115
6.1 Introduction 115
6.2 Case Description and Case Design 116
6.3 Methodology 117
6.4 Analysis and Results 118
6.4.1 TRIZ- DVR: Voltage Sag Problem Definition 118
6.4.2 TRIZ-DVR: Resources 119
6.4.3 TRIZ-DVR: Ideal Final Result 119
6.4.4 TRIZ-DVR: TESE Standing 119
6.4.5 TRIZ- DVR: S-Curve Standing 120
6.4.6 TRIZ-DVR: Contradictions Mapping Result 121
6.5 Results Summary and Discussion 122
6.7 Conclusions 127

7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH 128
7.1 Research Summary 128
7.2 Contributions 131
7.3 Conclusions 132
7.4 Recommendations for Future Work 132

REFERENCES 136
APPENDICES 146
BIODATA OF STUDENT 150
LIST OF PUBLICATIONS 151

LIST OF TABLES

Table	Page
2.1. PDCA cycle activities for implementation	19
2.2. Comparison and contrast of different innovation methodologies	40
2.3. Established TRIZ methods and toolset	43
3.1. DVR's analysis with TRIZ Trends of Engineering System Evolution	61
3.2. DVR's standing analysis along TRIZ S-curves development life cycle	63
3.3. DVR's analysis by Contradiction Matrix Mapping	66
3.4. Conceptual directions and guidelines derived for DVR	68
4.1. Sustainable development issues and related TRIZ tools	78
4.2. Five principles that appear with the highest frequency	84
4.3. Five principles that appear with the highest frequency	85
4.4. The principles that appear with the highest frequency as Environmental and Energy characteristics improving candidates	86
4.5. Future strategic directions for energy developments and TRIZ trends of evolution	87
4.6. Directions for energy workers for most probable sustainable energy related development	90
5.1. List of sorted Smart Grid – Asset management KPIs and TRIZ engineering parameters	103
5.2. List of main and sub-trends derived for TRIZ 'Trends of Engineering System Evolution'	106
5.3. Results for s-curve standing indicators and recommendations	107
5.4. List of 'smart grid – asset management' related TRIZ IPs	108
5.5. TRIZ based guidelines summarized for 'smart grid-asset management' related developments	110
6.1. TRIZ TESE analysis for DVR response time	120

6.2. TRIZ S-Curve analysis for DVR response time 121

6.3. TRIZ Contradictions Matrix analysis for DVR response time 122

6.4. Frequency distribution table of feedback 124

LIST OF FIGURES

Figure	Page
1.1. Research general methodology stepwise description	8
1.2. Method of analysis for research- stepwise description	9
1.3. Verification of methodology from research resources	10
2.1. Five generic steps of engineering design process	17
2.2. A simple Ishikawa Fishbone diagram	21
2.3. TRIZ – A tool, a method and a Philosophy	31
2.4. TRIZ guidance domain for Electrical Engineering solution design	47
3.1. Methodology flow chart for generating sector specific guidance	55
3.2. Case specific methodology flow chart for generating guidance for DVR	56
3.3. Steps towards development of guidance framework for DVR	57
3.4. TRIZ system operator – expansion along time and space axis	58
3.5. S-Curve DVR's standing for MPVs – Stage 2 and Stage 3	65
3.6. Proposed methodology for using the guidance framework for DVR	70
4.1. Methodology chart for sustainable energy development guidance framework	75
4.2. Steps towards guidance generation for sustainable energy development case	76
4.3. Flowchart of green innovation design method	82
4.4. Frequency of TRIZ 40 principles with respect to the Environmental Engineering Characteristic contradictions	83
4.5. Frequency of TRIZ 40 principles with respect to the energy saving characteristic # 19, 20 and 22	84
4.6. Probable IFR chart for energy scenario	89
4.7. Methodology chart for seeking sustainable energy development related solution	91

5.1. Average (Yellow rectangle) and Range of Maturity Scores by Domain 99

5.2. Methodology for generating guidance for Smart gird –Asset Management developments in future 101

5.3. Steps towards guidance generation for asset management case 102

5.4. Methodology chart for seeking smart grid-asset management development related solution 112

7.1.Architecture of proposed 'Value Engineering' knowlege management 135

LIST OF ABBREVIATIONS

AFD	Anticipatory Failure Determination
BA	Bionic Association
BS	Brainstorming
CSCI	Climate Saved Computing Initiative
DoE	Department of Energy
DPE	Direct Product Evaluation
DVR	Dynamic Voltage Restorer
EEC	Environmental Engineering Characteristic
ES	Engineering System
IEA	International Energy Agency
ICT	Information and Communications Technology
IFR	Ideal Final Result
IP	Inventive Principle
KMS	Knowledge Management System
KPI	Key Performance Indicator

KTA	Key Technology Areas
MPV	Main Parameter of Value
NETL	National Energy Technology Laboratory
PDCA	Plan, Do, Check, Act
RPN	Risk Priority Number
SEI	Software Engineering Institute
SGMM	Smart Grid Maturity Model
TRIZ	Theory of Inventive Problem Solving
TESE	Trends of Engineering System Evolution
VE	Value Engineering
WBCSD	World Business Council for Sustainable Development

CHAPTER 1

INTRODUCTION

1.1 Background

For engineering systems in industries and enhancement in their performance, engineers have always been working to find better solutions. Focus of engineers is mostly the technical problems, arising from engineering systems involved in performing different tasks. As a solution, different new technologies have been introduced over the time to replace or enhance less efficient or problematic systems. These new technological inventions are output of a continuous process starting from a feel of need and originating as a solution idea in human mind. Engineering is the process of turning those ideas into reality by defining the concepts and implementing those into physical systems/products. This creative act of turning ideas into technological concepts and ultimately into a physical product (engineering system) is called engineering design. Most of the existing inventions/systems are output of creative human efforts which did not exist before or are improvements in some previously existing systems. For reasons, the engineers are known as "problem solvers", who address some need/problem of a current scenario and are supposed to come up with some practical solution [1].

The complexity of engineering systems as well as need of expertise in multiple fields for dealing with problems has been increasing with passage of time. In process of finding solution for an engineering problem, the project team is supposed to tackle a problem

which is usually characterized by many requirements and objectives, some of which are conflicting.

Electrical engineering domain is the prime focus of this research for implementation of proposed research concept. The integration of different technologies (e.g. electrical devices, electronic devices, ICT equipment, Automation equipment etc) as part of one engineering system makes it very challenging for engineers to understand the root cause of problems and come up with better solutions, while meeting resources and time limitations simultaneously. Ever increasing technological inclusions e.g. distributed generation of power from multiple resources and need to manage/monitor power consumption smartly for best usage of available power are example of added complexity and integration of technologies in power systems [2]. Much higher expertise and knowledge of multiple fields are required to seek a comprehensive efficient solution, which ultimately need bigger project teams with higher expertise at behalf of engineers (problem solvers). For this solution hunting, Dekker discusses the best solution as the one which meets all requirements and staying within constraints of time and resouces [3].

1.2 Conventional Solution Techniques and Current Needs

At one hand, engineers as problem solvers are supposed to bring best possible solutions meeting all requirements with least cost, time and resources. On the other hand, with the growing age of technology, engineering systems are becoming more and more complex

and difficult to handle. The complexity of engineering systems and integration of different technologies makes it very challenging for engineers to understand the root cause of problems and come up with better solutions. All this means, broader range of knowledge in multiple fields, higher expertise to address latest issues, striving for optimum solution within resources and meeting objectives with least time and cost to stay competitive in market. Conventional solution seeking methods are not being sufficiently capable of addressing the ever growing complexity of solution hunting in complex scenarios [4]. Engineers using conventional solution finding methods like PDCA, Six-sigma, Ishikawa diagram etc are still in need of more support for effectively meeting complexity of problems.

Also to stay competitive in today's fierce competition, innovative and breakthrough solutions are need of the time. Established conventional methodologies/techniques for obtaining innovative solution ideas like brainstorming, 5 Ws, lateral thinking, combination method etc are more about random ideas generation, not systematically guiding and often neither producing something concrete, to the point and scientifically validated. Also, results from these conventional techniques mostly rely on and limited to project workers' perspective, professional experience and knowledge background.

1.3 Theory of Inventive Problem Solving (TRIZ)

TRIZ is a methodology, tool set, knowledge base, and model-based technology for generating innovative ideas and solutions for problem solving. TRIZ provides tools and methods for use in problem formulation, system analysis, failure analysis, and patterns of system evolution (both 'as-is' and 'could be'). TRIZ aims to create a systematic approach to the invention of new systems, and the refinement of old systems [5 - 6].

The main traits or advantages of using TRIZ methodology are [5 – 7]:

- systematic,
- innovative knowledge base,
- broadening vision for solutions beyond specific field,
- guidance for probable future transitions, and
- good range of tools.

Contrary to conventional techniques, TRIZ is a knowledge-based creativity technique. TRIZ is equipped with a group of technical tools and methods and provides a comprehensive approach to create innovative solutions for problems. For meeting today's challenges of complexity, need of innovation and foreseeing future, TRIZ has strong capability of addressing all needs most effectively as compared to conventional engineering design and innovation techniques/methods (Section 1.3).

Rather than searching out an optimal solution from a big collection of ideas randomly, TRIZ first simplifies problems to their basic formats, forcing a complete understanding of the essential problems. Next, TRIZ will offer methods and tools to refine solution search systematically. It provides solution vision of the methodologies that have been successfully used to solve similar problems in the past. TRIZ's intellectual power does not depend on the participants' presence or their collective imagination. Instead, it is embedded in TRIZ's methods and tools, which are derived from the analysis of 2.5 million patents across industries and domains [8].

1.4 Problem Statement

The intricacy of engineering systems is increasing with integration of multiple technologies as one system. It is becoming hard for engineers to address problems in a system, which needs expertise in multiple technological domains. Moreover, because of the continuous development of technologies, the engineering systems are very developed and mature in most of the fields. The problems arising and needs emerging in already developed engineering systems often need some breakthrough innovative solution to make practical difference in competitive market (Section 1.1). To help engineers find potential solutions and foresee future developments in some sector, today's conventional methods and tools are not being sufficient. There should be some guidance which systematically guides engineers through process of solution hunting or development (Section 1.2). This systematic support should help engineers to cater the difficulty in engineering solution hunting, guides them for potential solution directions

more accurately (based on some scientific evidence) and make them think out of the box for innovative solutions (beyond personal field experience and learning). As the systematic process is aimed to be less complex, hence it should help in meeting challenges of competitive markets with cost and time effective solution search.

This research seeks to utilize potential of TRIZ for addressing the increased intricacy scenario for engineering solutions (section 1.1 - 1.3). However, with current scenario, utilizing TRIZ knowledgebase is not an easy task for engineers (who are not TRIZ experts to a certain high extent). Higher TRIZ expertise is needed and hence TRIZ experts are a need of solution seeking process to cash the benefits of TRIZ. Secondly, TRIZ knowledgebase is an extended database covering multiple scientific disciplines on an abstract (generic) level. Some of the tools and methods may not be applicable to some sectors/problems and may sound difficult to apply. More simplified and sector specific guidance should be derived from TRIZ database, that may lead towards something more viable and simplified to use by regular engineers. The problem statement in this scenario may be summarized as in following points:

- complexity of electrical systems is growing with integration of multiple technologies as part of one system,
- the situation increasing challenges as need of higher expertise in multiple fields, more time and more costs for project teams,
- conventional solution techniques are not being sufficient in assisting engineers to meet growing challenge effectively,

- more structured and systematic knowledge based tools like TRIZ may support engineers for better solutions, and
- application of TRIZ in electrical system and making the utilization of TRIZ knowledgebase simplified for regular engineers may need to be sorted out for development of such support

1.5 Research Objectives

The objectives for this research to develop sector specific guidance are summarized as:

1- To derive a methodology/technique for development of sector specific guidance using TRIZ for electrical engineering domain.

2- To develop sector specific guidance frameworks for three cases (sub-domains) from electrical engineering domain, to show 'how to build the proposed guidance' for different sectors with diverse aspects/needs/requirements.

3- To validate the sector specific guidance approach by application of results on a real existing problem in engineering systems.

1.6 Research Methodology

The research mainly took qualitative approach towards working out the aimed objectives. Qualitative research literature was referred for validated and well accepted approaches to address a problem, choosing samples, collect data, making analysis and to derive results. The general research methodology is summarized along with strong references from qualitative research literature, as in following stepwise chart:

1.6.1 Methodology Description

Following stepwise explanation for methodology is presented to cover general research approach, strategy, data collection method, sources and sampling for this research.

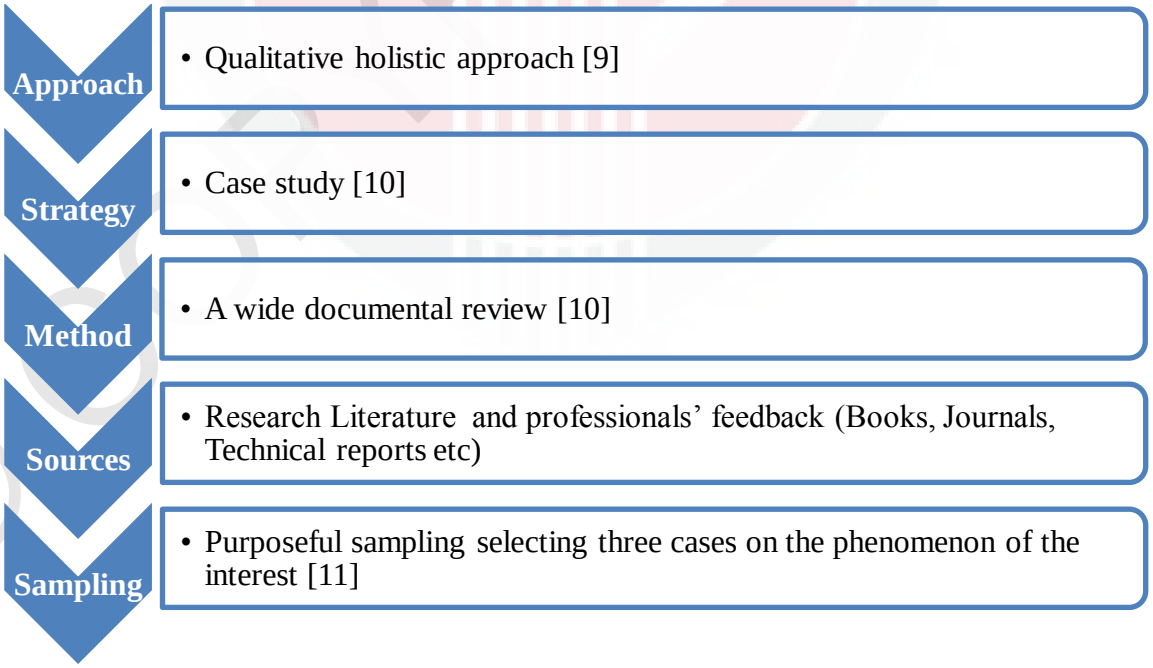

Figure 1.1. Research general methodology stepwise description

1.6.2 Method of Analysis

Following stepwise explanation summarizes general method of analysis opted for this research in broader aspects.

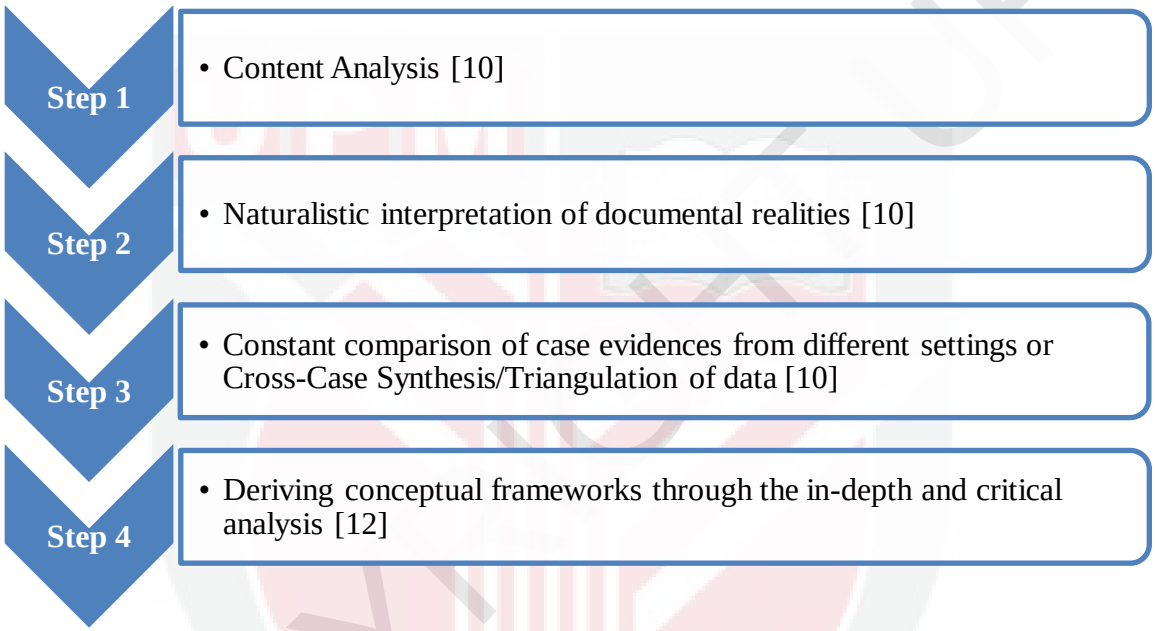

Figure 1.2. Method of analysis for research- stepwise description

1.6.3 Verification of Methodology

Following stepwise explanation summarizes the validation approach taken for chosen methodology of research and methods of analysis.

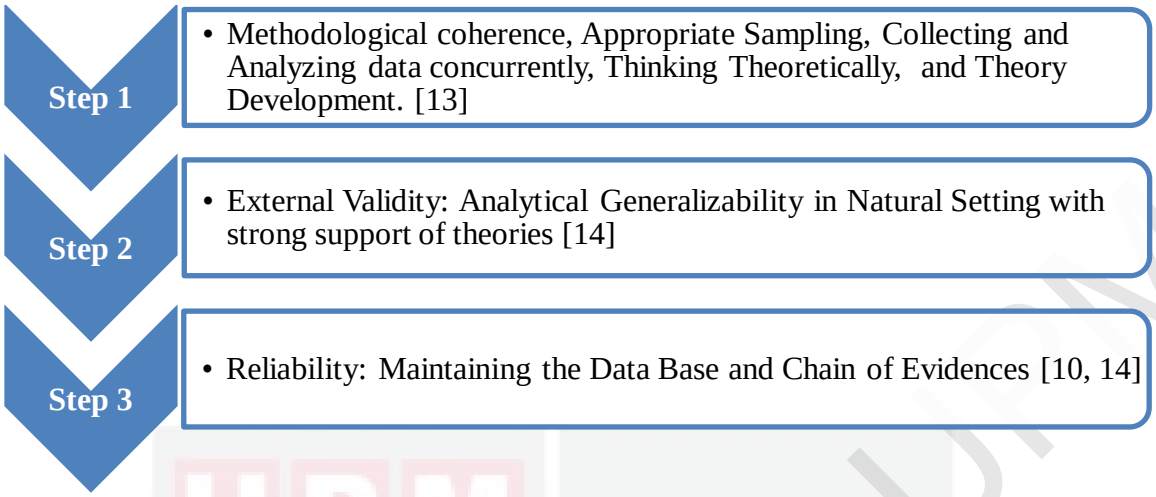

Figure 1.3. Verification of methodology from research resources

1.7 Benefits, Scope and Limitations

1.7.1 Benefits

The proposed research of working out knowledge based guidance for smaller sectors of electrical engineering will provide the following benefits:

1- It will provide a novel approach to build TRIZ based conceptual guidance, for potential directions of sought solutions in electrical engineering domain. The developed guidance will not be problem specific rather it will be sector specific, optimized to one sub-sector of engineering systems.

2- It will simplify TRIZ usage for a specific sector. Hence, it will reduce need of a TRIZ expert at first place in dealing a problem in a specific sector, while seeking

help from TRIZ (One basic hurdle in TRIZ methodology usage expansion). By reducing difficulty in solution hunting and providing structured guidance, it will reduce time and costs associated with solution hunting process.

3- Utilization of patents' originated knowledgebase will help in breakthrough solutions and innovative ideas for strong conceptual solution ultimately resulting in more practical and effective solutions. It will help in generation of new creative ideas to seek future transitions of engineering systems in specific sector.

1.7.2 Scope and Limitations

This research was conducted with aim to build effective sector specific guidance, which can support engineers/problem solvers working in some specific field. Although this approach built a successful way for working out sector specific knowledgebased guidance, the research still can be refined and developed further to more indepth analysis of some sector. This may need TRIZ experts as well as sub-sector/field experts to workout together for a sector specific guidance in detail. The output of this research mainly shows the capability of TRIZ to address different scenarios and aspects of a major field (electrical engineering in this research). It mainly develops and demonstrates the steps and possible ways to utilize TRIZ knowledgebase alongwith field specific knowledge to develop sector specific generic guidance (without going very deep into the minor details of a field). Although it simplifies the TRIZ knowledgebase utilization and

reduce need to TRIZ experts, the guidance charts developed by this research may still need some basic understanding of TRIZ approach for making best use of it.

1.8 Thesis Organization

To meet the objectives of this research, the work was divided into the following work packages:

- literature review,
- initial research and pilot case study,
- case studies selection,
- data collection,
- implementation of research methodology and results' analysis,
- validation of research, and
- concluding research and research writings.

To document the completed work in work packages, this thesis is divided into seven chapters. Chapter 1 introduces the research proposal and summarizes the overall research need, contributions and steps towards working out the research. It briefly explains the purpose and background of research while putting light briefly on all core sections of this research. Chapter 2 details the research literature referred for addressing the problem in focus. It covers all core parts related to research proposal, problem statement and objectives of this research. State of the art literature on the subject is referred and built hypothesis are justified with reference to validated research literature.

It includes some details on TRIZ and the methodology used for research in TRIZ purview.

Chapters 3-5 present details of three case studies conducted for implementation of research methodology. The details of results obtained in each case study are presented as separate chapter. Chapter 6 presents implementation of the research results to validate the research approach and results achieved. It takes a real industrial problem "DVR response time" for utilization of developed guidance chart and summarizes the results achieved to support findings of this research.

Chapter 7 summarizes overall research and concludes the findings. It further proposes the future work to be done to enhance these research findings in future. It also presents some suggestion that how to carry out the proposed research enhancements in purview of the research literature available in this regard.

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