ARTICLE IN PRESS

Renewable and Sustainable Energy Reviews (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Innovating problem solving in power quality devices: A survey based on Dynamic Voltage Restorer case (DVR)

Muhammad Mansoor[a,b], Norman Mariun[a,*], Arash Toudeshki[a], Noor Izzri Abdul Wahab[a], Ahmad Umair Mian[c], Mojgan Hojabri[d]

[a] *Centre for Advanced Power and Energy Research (CAPER), Faculty of Engineering, University Putra Malaysia, UPM, Serdang 43400 Selangor, Malaysia*
[b] *Pakistan Institute of Engineering and Technology, Multan, Pakistan*
[c] *Key Laboratory of Universal Wireless Communications, Ministry of Education, Beijing University of Post and Telecom, Beijing, China*
[d] *Faculty of Electrical and Electronics Engineering, University Malaysia Pahang, Pekan 26600, Malaysia*

ARTICLE INFO

Keywords:
TRIZ
Complexity
Power quality
Guidance framework

ABSTRACT

The theory of inventive problem solving (TRIZ) is one of emerging creative problem solving methodologies. This paper proposes a way to simplify TRIZ for electrical domain usage, while making it feel less complex, more relevant and understand able for users in a specific sector. This research takes Dynamic Voltage Restorer (DVR) device as a case from electrical engineering domain, to demonstrate the proposed TRIZ based guidance framework development which will assist in solving problems of DVR devices. The proposed sector specific guidelines in particular segment of Electrical Engineering (e.g. power quality device DVR) will be closer, more comprehensible and particularly linked to key parameters of that sector. By using the derived guidance framework, field engineers with very basic TRIZ knowledge may apply TRIZ confidently for design and problem solving purpose.

1. Introduction

Researchers have always been working on improvement of existing systems and removing their deficiencies. With increasing technological development, systems today are more mature and sophisticated. To add further improvement in already mature technologies, researchers do try to bring creative and practical breakthrough ideas. Different innovative and creative methodologies have emerged to generate better solutions to address existing deficiencies in systems. Over the past few decades, TRIZ has been gaining repute for its capability of offering systematic innovation and breakthrough creative ideas. Developed by Generic Altshuller and his companions in 1960s, TRIZ development followed a conception that there exist basic principles, patterns and laws which govern process of solving a problem and creating new ideas. For deriving those principles, patterns and laws, Generic Altshuller and his companions analyzed 400,000 patents and sorted a knowledgebase based on those derived principles. TRIZ also referred as a toolkit by few researchers, is regarded by some as the best comprehensive, most systematically organized tool kit for invention and creative thinking methodology in existence [4,6] (Chang Y.S, 2016). Originally developed for technological solutions, TRIZ now have been applied to various fields including management and social sciences.

Although TRIZ has been gaining strength in past two decades since it moved to west, it still has been regarded as a controversial scientific approach by masses. The TRIZ usage still remains below expected figures because of certain prevailing issues and conceptions. A comprehensive analysis work by Ilevbare et al. [4] analyzes TRIZ conceptions, what does it offer and what are the issues still faced by TRIZ for its application expansion. The research concludes that “TRIZ appears to be a complex approach that requires substantial effort and commitment to understand and lacks an accepted standard for its application. TRIZ is enigmatic in nature, while it seems to offer clarity to problem solving and innovation, there is great confusion on how to approach it and what exactly it embodies and this makes it difficult to fully grasp” [4]. Seemingly complex, irrelevant to field and difficult to apply are quiet widespread words and conceptions put forward by users who are initially introduced to TRIZ.

With reference to conclusions by Ilevbare et al. [4], this study aimed at showing possibility of removing conceptions about enigmatic nature of TRIZ and difficulty to understand it for common use. The paper chose to develop a simplified sector specific TRIZ guidance example, which is more understandable and feel less alien to someone with no or minimal TRIZ knowledge. It meant to build relation (mapping) between chosen case from Electrical Engineering domain and TRIZ

* Corresponding author at: Centre for Advanced Power and Energy Research (CAPER), Faculty of Engineering, University Putra Malaysia, UPM, Serdang 43400 Selangor, Malaysia
E-mail addresses: mansoor.upm@gmail.com (M. Mansoor), norman@eng.upm.edu.my (N. Mariun).

http://dx.doi.org/10.1016/j.rser.2016.12.022

1364-0321/

Please cite this article as: Mansoor, M., Renewable and Sustainable Energy Reviews (2016), http://dx.doi.org/10.1016/j.rser.2016.12.022

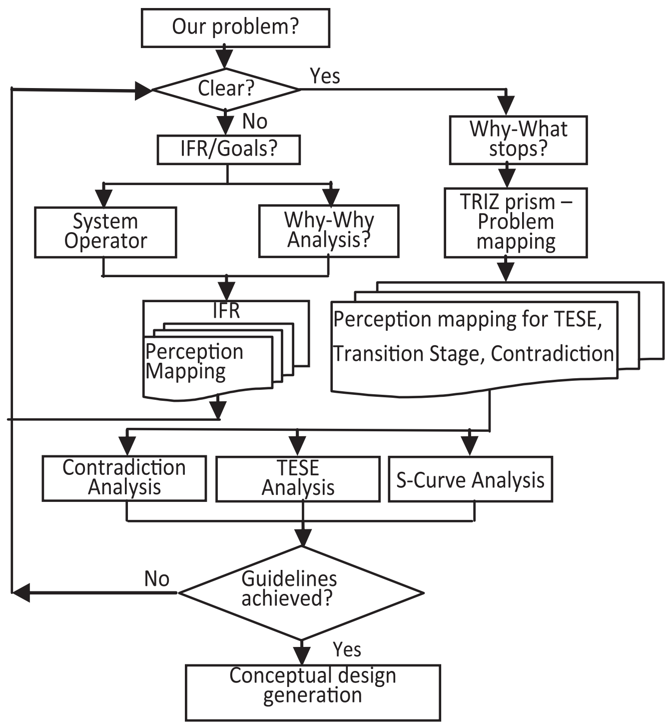


Fig. 1. Methodology flow chart for generating guidance over DVR shortcomings.

	Past	Present	Future
Super –System			
System	Before DVR protection	DVR protection running	After SAG event
Sub-system			

Fig. 2. TRIZ system operator – expansion along time and space axis.

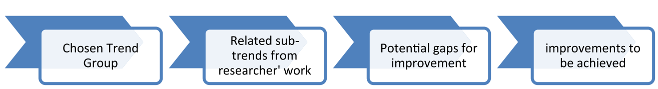


Fig. 3. The process steps followed for R-Plot Analysis.

to provide the missing link. Furthermore, it targeted to show positive support of achieved guidance results for thinking process of solution seekers and problem solvers in that particular device field. The paper documents the proposed way to simplify TRIZ application by making it seem more relevant and associated to key factors of a smaller sector within a scientific discipline. The technical problem to demonstrate the execution of proposed research is taken from electrical engineering domain, as successful usage of TRIZ has already been recorded in research literature for particular problems from electrical engineering domain, which supports the idea presented here [1,11,12,13,7]. The approach here presents the idea of generating a generic guidance framework which is not problem specific; rather it is sector specific and generic for a smaller sector. The process of generating guidance framework for a specific sector may include TRIZ experts and aimed field experts to work together for an initial framework. Later, the developed frame work can be used by regular field engineers (problem solvers) with basic knowledge of TRIZ (they don't need to attain a higher level TRIZ practitioner's status to take benefit from TRIZ). It is because the developed sector specific guidelines will be closer, more detailed and particularly linked to key factors and parameters of one small sector, as compared to whole TRIZ database, out of which major knowledge chunk may not make sense to some new users.

2. Research approach and methodology

To demonstrate, how to build the TRIZ based conceptual guidance frameworks for a smaller sector, this paper takes a case for an example from electrical devices related to energy and power quality issues. As specific sector to address, the field of energy efficiency (power quality improvement) is focused, which has been discussed in relation to barriers of energy efficiency and possible conceptual frameworks to address [5]. It chooses "Dynamic Voltage Restorer (DVR) device" which is a known solution for voltage sag problems in electrical systems. It analyzes the current problem addressing scenario, builds and defines the parameters in TRIZ prism for DVR, set some MPVs (Main Parameters of Value) and analyze the current SAG solution (DVR) standing by mapping all parameters to TRIZ database. Using different outputs of one method/tool as input to next method/tool and processing this information leading towards a possible set of guidance converging as a sector specific guidance chart for DVR improvements. It derives the proposed conceptual guidance framework for future development of DVR solutions, to cater deficiencies in today's DVR-SAG solutions. The analysis has used methodology (as depicted in Fig. 1), which is derived from TRIZ researchers' work [8,10,14,9].

3. DVR analysis and development of conceptual guidance framework

According to purview of this research, it takes an approach for building a generic conceptual level guidance summary for addressing DVR's current deficiencies and doesn't look for converging to problem specific solutions at this stage. The details of analysis and results are summarized as following steps in accordance of the methodology chart in Fig. 1. Keeping this documentation brief and concise, this is how it is worked out.

3.1. Problem definition – exploring shortcomings in DVR

System Operator (9-windows) and Why-Why Analysis tools of TRIZ are used for problem exploration and definition [8]. The 9-windows tool helps in expanding the failure scenario of SAG protection (DVR) working in some electrical system along the time and space axis (Fig. 2). The output of this analysis, i.e. the problems in DVR found for different failure/inefficiency/undesired scenarios is summarized in points below. Keeping this documentation brief and concise, the key findings were noted. The results have shown major issues present in current DVR solutions as:

1. Reliability of DRV protection is vulnerable. In case of "multiple SAGs following each other entering a system at a faster rate than hold up capacitor's recharge time". (response time)
2. Size and weight of DVR (Size of transformer, switch and other major components)
3. Flexibility of usage of available DVRs in multiple scenario of variable system loading
4. Costs of DVR introduction, installation, running and maintenance – expensive
5. Efficiency of DVR (losses in transformer, switching etc)

3.2. Resources

The problem definition analysis also shows some potential resources available in super-system for integration and potential use to cater problems within the running system. Resources like atmosphere factors around (TRIZ concept of even the negative is positive), other power system components installed in surrounding, available fast digital technologies and AI tools are some important ones amongst them.

Table 1:
DVR's analysis with TRIZ Trends of Engineering System Evolution.

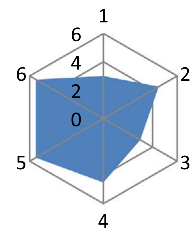
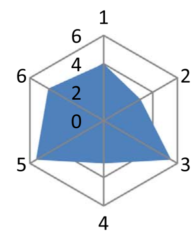
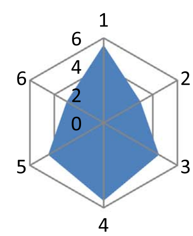
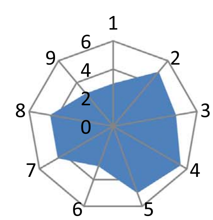
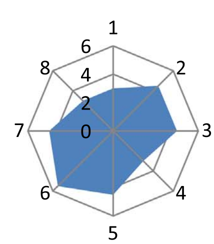
Trends - group	Sub-Trends (inferred from the researches)	Potential Gap – Resources (Most potential GAPs)	R-Plot Graph	Suggested Reasons for jumps to next transition stage
Trend of Transition to Super-System	1- Heterogeneity of integration 2- Degree of integration depth 3- Variety of integrated systems 4- Mono-Bi-Poly (interface) 5- Boundary breakdown (space) 6- Reducing energy conversions	1- Heterogeneity of integration, 2- Variety of integrated systems		- To improve variety of features, functionality, use of super-system resources, reliability. - Reduce cost, size, weight, waste/losses, system complexity.
Trend of Increasing Completeness	1- Level of self containment 2- Degree of freedom 3- Use of senses 4- Design methodology 5- Design point 6- Coordination within and with supersystem	1- level of self containment 2- degree of freedom 3- design methodology		- To improve operability, reliability, dynamic use - Reducing design wastes (time and cost)
Trend of Increased Trimming	1- Sub-system trimming 2- Operations trimming 3- Low value component trimming 4- Reducing energy conversions 5- Boundary breakdown 6- Nesting (time+interface)	1- Operations trimming 2- Nesting (time and interface)		- To reduce size, system complexity. - To improve use of system resources, time efficiency.
Trend of Flow Enhancement + Trend of Coordination + Trend of Controllability	1- Damping 2- Senses interaction 3- Feedback/feed-forward control 4- Action coordination 5- Rhythm coordination 6- Nesting (time and interface) 7- Design methodology (adv coordination plan) 8- Level of control 9- No. of states of control	1- Damping 2- Nesting (time and interface) 3- No. of states of control		- To reduce energy loss, size, time. - To improve dynamic performance, response time.
Trend of increasing Dynamization	1- Substance dynamization 2- field dynamization 3- Composition dynamization 4- Function dynamization 5- Mono-Bi-Poly (time+interface) 6- Process thinking/design point 7- Macro to Nano scale 8- Smart materials	1- Substance dynamization 2- Function dynamization 3- Smart materials		- To improve flexibility, control, features offered, efficiency. - To reduce cost, size, energy loss.

Table 2:
DVR's standing analysis along TRIZ S-curves development life cycle.

MPV	Factors to consider and map (derived from TESE and Problem definition)	S-curve standing	S-curve standing indicators (From TRIZ knowledge base mapping)	Recommendations for future working (From TRIZ knowledge base mapping)
Reliability	– Never fail – Immediate response – Precise corrective action	**Stage –3:** Maturity and saturation situation	– ES has reached some development limits (limited by contradiction of size VS power, (20 ms for 50 Hz)) – ES generations mainly differ by design and functions – Incremental improvement of ES requires disproportionate resources – ES used specialized resources – MPVs change slowly	– Short/medium term: Reduce costs, develop service subsystems, improve design – Long term: Switch principle of action for ES or its components (which resolves the contradiction/breaking the limits for further development) – Transition to super-system, deep trimming, integration to alternative systems.
Size/Weight	– Space covered – Ease of movement – Ease of maintenance – Ease of installation			
Flexibility	– Type of features offered – Variety of features offered – Ease of usage at multiple locations – Ease of usage in multiple scenarios/Range – Easy upgrade	**Stage - 2:** Fast growth achieved with further margin of development	– ES has not reached its development limits – A number of potential niches – Uses existed support system – Linear relationship between improvements made and resources required – ES gains functions, closely related to main function – ES start consuming ES-specific resources/ specialized resources. – Differentiation among different system types grows – difference between system generations increase and then decrease almost to zero/ modifications very high at first and become less varied toward the end of stage	– Optimization is the principle method for improving the system – Adapt ES to new applications – Use of resources specially adapted to the ES from super-system is possible(look for potential resources in super-system – Moderate changes should be introduced to the system design and design of system components (without changing their principles of operation) – It is possible to focus on compromises and solutions aimed at limiting disadvantages, without eliminating entirely. – Can assume the existence of ES specialized resources – Adding components can be as useful as trimming for improvement
Cost	– Initial cost – Installation Costs – Maintenance Costs – Operational Costs – Work Life			
Efficiency	– Type of losses associated – Losses within DVR – Losses in super-system because of installation – Operational losses – Compensation time losses			
Complexity	– Ease of operation – Ease of understanding – Ease of installation			

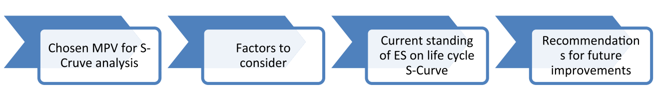


Fig. 4. The process steps followed for S-Curve analysis.

3.3. Ideal final result

Ideal Final Result, a tool of TRIZ, was used to do the right perception mapping for the ideal output desired by all involved parties i.e. the customer, the manufacturer and the engineers. After developing lists of desired output by all stake holders separately and detailed analysis for functions and values sought from DVR, the ideal final result (sought by all stake holders' perception mapping) as one concise statement concluded was “With least costs, minimum installation size, least complexity, no wear and tear, no additional maintenance introduction, no technical losses and 100% corrective perfection (no delay, in phase, no additional harmonics etc), DVR should always address the problem of any range of SAG entering the variable loading electrical

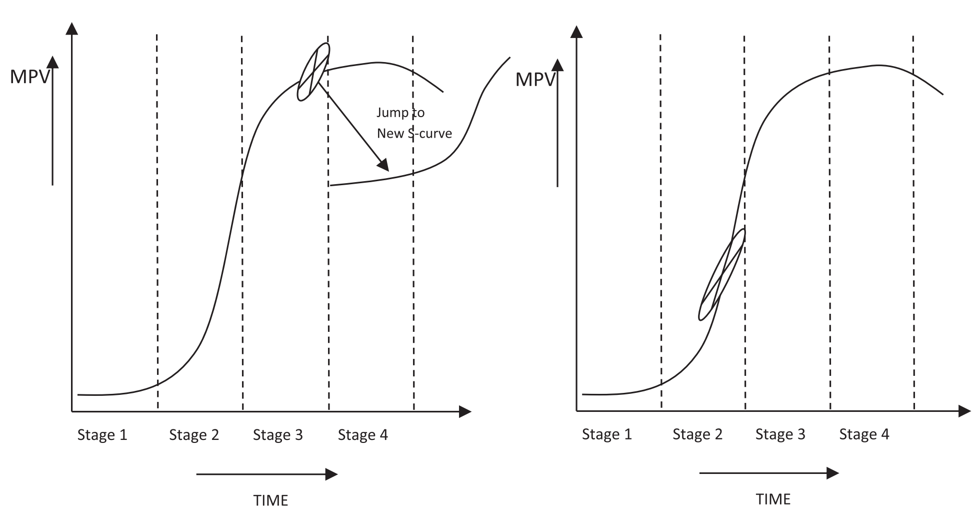


Fig. 5. S-Curve DVR's standing for MPVs.

Table 3:
DVR's analysis by Contradiction Matrix mapping.

Sore points (9-windows+Y-Y+IFR derived points)		TRIZ parameters (Abstract level parameters by TRIZ mapping)		Solution ideas – Conceptual solution direction (Mapping with TRIZ patent knowledge base)
Issue	**Root cause**	**Improving parameter**	**Worsening parameter**	
Multiple SAGs approaching system fails the DVR protection	Response Time is limited to system frequency – 50 Hz (20 ms)	1- Speed	1- Accuracy 2- Reliability	– Intermediary – Mechanic substitution – Relative Change – Color change – Segmentation – Beforehand cushioning – Parameters changes – Cheap short living object (disposable)
Size, weight and losses of DVR are high because of need of higher power	Transformer size is big and heavy for higher power needed (more windings etc) – “vice versa” More power is associated to more losses –	1- Power	1- Weight of stationary object 2- Volume of stationary object 3- Loss of energy 4- Temperature	– Periodic action – another dimension – copying – cheap short-living objects (disposables) – Self service – Flexible shells and thin films – Universality (multi-functioning) – preliminary action /prior action (do it in advance) – Parameter changes – Strong oxidants – Taking out (extraction) – Curvature
DVR isn’t very flexible and wide range device	For covering higher ranges and longer times, backup supply is limited by cost	1- Reliability 2- Adaptivity/ Versatility	1- Productivity	– Segmentation – Parameter changes – Pneumatics and hydraulics – Strong oxidants – Mechanical substitution – Thermal expansion – Universality (Multi-functionallity)

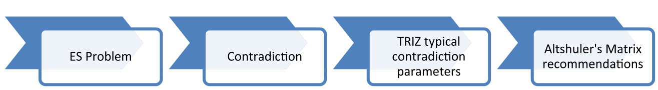


Fig. 6. The process steps followed for Contradiction Matrix mapping.

system”.

3.4. *DVR's standing along TRIZ Trends of Engineering System Evolution (TESE)*

All the Engineering Systems (ESs) develop along a trend named as “Trend of increasing value” [3], where

Value=benefit/cost (value equation).

The Radar plot provides a depiction of Engineering System's (ES's) current status along the engineering system generic transition states/ trends defined by TRIZ researchers [8]. Standing of DVR along the proposed engineering system's transition stages (derived from patent's database analysis by TRIZ researchers) is drawn at a Radar plot to show how much value it had gained. This provides overview of the gaps in system maturity/transitional development possibility, along the pre-determined engineering system development paths.

For comprehensive transitional view of our ES, DVR's transitional standing is depicted by Radar-plots of “seven main groups of transitional trends”. The sub-trends for these Radar-plots were derived by grouping of transitional parameters and trends, defined in TRIZ by researchers for seven main trend groups [3,9,8,10]. The process followed for deriving guidance by radar plot analysis is depicted in Fig. 3.

For seven trends groups, following are the results of mapping and inference from TRIZ patent knowledgebase (Table 1). Furthermore, three trends i.e. Trend of Flow Enhancement, Trend of Coordination, Trend of Controllability are grouped at a single R-plot because of similarity of sub-parameters. The radar scale was set with a count of 6-levels for all R-plots, for sake of plotting trend transition standing at a similar scale:

From the GAPs elaborated by analysis above, more potential directions of working are the ones with highest GAP (least ES trends transition achieved). From summary in column-3 of Table 1 “most potential GAPs”, major reasons to try a jump are described as per mapping output from TRIZ patent knowledge base. The results conclude that for improving operations and present deficiencies of DVR, most preferred working is needed in dimensions of reducing energy losses, reducing cost, size and weight of a DVR, increasing flexibility of functioning and reliability of system.

This can be achieved by thinking in dimensions of “Possible trends transition” short listed above as system integration with other systems around in super-system to achieve more variety in functions and covering a better operational range. More dynamics within system and components is needed for flexibility as well as control. Better degree of freedom is most probably achieved by increasing number of control states working from Macro to Nano scale of control and using smart materials to enhance efficiency. By nesting up internal operations’ time and over structural interface niches, will result in cutting off processing time and size/weight of equipment. Thinking on dimensions of damping reduction will reduce losses and can be achieved by integration with super-system and shifting of functions for reducing number of energy conversions.

Table 4:
Conceptual directions and guidelines derived for DVR.

Chosen Issues in DVR problems definition analysis	Main DVR related TRIZ parameters	S-curve derived results – Future development directions	TESE derived results – Future development directions	Contradiction Matrix derived Inventive principles – breaking limitations
limited response time because of accurate signal analysis for 50 Hz in put takes 20 ms (fundamental limitation) More power and reduced size sought – Transformer size is big and heavy for higher power needed (more windings etc) – (fundamental limitation) "VICE VERSA" More power/windings/flux is associated to more losses More wider range of application is desired – DVR isn't very flexible and wide range device	– Speed – Accuracy – Reliability – Power – Weight of stationary object – Volume of stationary object – Loss of energy – Temperature – Reliability – Adaptivity/ versatility – Productivity	– Switch principle of action for ES or its components, – Transition to super-system, – Trimming – Integration to alternative systems. – Develop service subsystems – Improve design – For non-fundamental limitation look for optimization – Adapt ES to new applications – Moderate changes to the system design and components' design of system components – Compromises aimed at limiting disadvantages, without eliminating entirely. – Can assume optimized components for system	**Transition for:** – Increasing heterogeneity in integration – variety of systems integration – Higher degree of freedom – Enhancement of trimming towards super-system and within system – Nesting up time of operations – Nesting up interface of system components – Reducing Damping and energy conversions – Increased number of control states – Higher dynamization for field, substance, functions – Usage of smart materials	1. Intermediary 2. Self service 3. Relative Change 4. Segmentation 5. Beforehand cushioning 6. Parameters changes 7. Cheap short living object 8. Periodic action 9. Another dimension 10. Copying 11. Flexible shells and thin films 12. preliminary /prior action 13. Taking out 14. Curvature 15. Pneumatics and hydraulics 16. Mechanical substitution 17. Universality (Multi-functional)

3.5. DVR's standing along TRIZ S-curves development life cycle

Evolution of ES against the MPVs varies in such a manner that the time dependence graphs of these parameters are in form of S-shaped curves [3,15]. In TRIZ, S-curves are qualitative description of current stage of ES in purview of an MPV. S-curve standing is decided by development of an ES over the time in purview of MPV chosen, which increases as a function of increasing value (Value=Total benefit/total costs+harm) over the time (TRIZ Trend of Increasing Value) [3]. From TRIZ database mapping, the reasons of DVR system standing at S-curve in purview of different MPVs and the suggested ways to move forward are summarized in Table 2. The process followed to derive guidelines by S-curve analysis is depicted in Fig. 4.

When an ES has reached some fundamental limitations and facing development problems, the S-curve of TRIZ depicts it as "time to look for a jump" on a new S-curve. This jump is usually defined by a breakthrough innovative solution to remove the fundamental limitation/contradiction/bottleneck stopping the system's growth. Conceptual guidance can be sought by looking into potential jumps suggested by S-curve indicators based directions and linking it to TESE development potential by TRIZ patent knowledge base.

In the ES, for the MPVs as chosen in Table 2, more potential of growth is along the second stage MPVs, where optimization is still a possibility (i.e. Cost, flexibility, efficiency, complexity) (Fig. 5). For MPVs, showing the system transition in third stage (i.e. Reliability, size/weight), more innovative and breakthrough solutions are needed to get further growth (Fig. 5). The backward and forward mapping through TRIZ tools output can guide engineers for a most probable direction to look for this breakthrough solution. It expands their solution space vision while reducing the complexity of random thinking at same time. Besides mapping and defining DVR in respect of different MPVs, Table 2 also summarizes possible generic steps to consider for further improvement of the ES in purview of specific MPV's stage.

3.6. DVR's analysis by Contradiction Matrix mapping

Using exploration of DVR's problems in problem definition work as discussed above, derived information is further critically processed for Why-What TRIZ analysis [9]. This resulted in finding root causes/bottle-necks present in different failure/inefficiency/undesired scenarios, figured out above in problem definition work.

For generating guidance to address the root causes/bottlenecks, "Why-What" analysis results are mapped to TRIZ generic parameters. Using these abstract level parameters of TRIZ, guidance is sought from TRIZ Contradiction-Matrix. The analysis results are summarized in tabular form as in Table 3 and the process is depicted in Fig. 6.

The analysis Table 3 summarized the problems in our ES (DVR) along with their root causes. Further defining the possible parameters involved in finding the solution directions from TRIZ abstract parameters list. Mapping above defined problems as "abstract level parameters" to TRIZ knowledge base resulted in possible steps denoted as "innovative principles", giving directions to consider for finding an innovative and effective solution for our present ES problems. The steps to choose in between and execute these innovation principles are further detailed in TRIZ database literature [14,15].

4. Derived framework summary and discussion

The reliability starts at conceptual design [2]. In the research case presented in this paper, a set of guidelines are derived from TRIZ patents' database for chosen ES (DVR) by mapping DVR's problems and deficiencies to abstract-level TRIZ parameters and universal innovative principles (Sections 3.1–3.6). The work done for deriving the guidelines in Section 3 is summarized in a single table form in this section (Table 4). The derived set of guidelines/chart presents most probable direction for thinking future solutions related to SAG/DVR

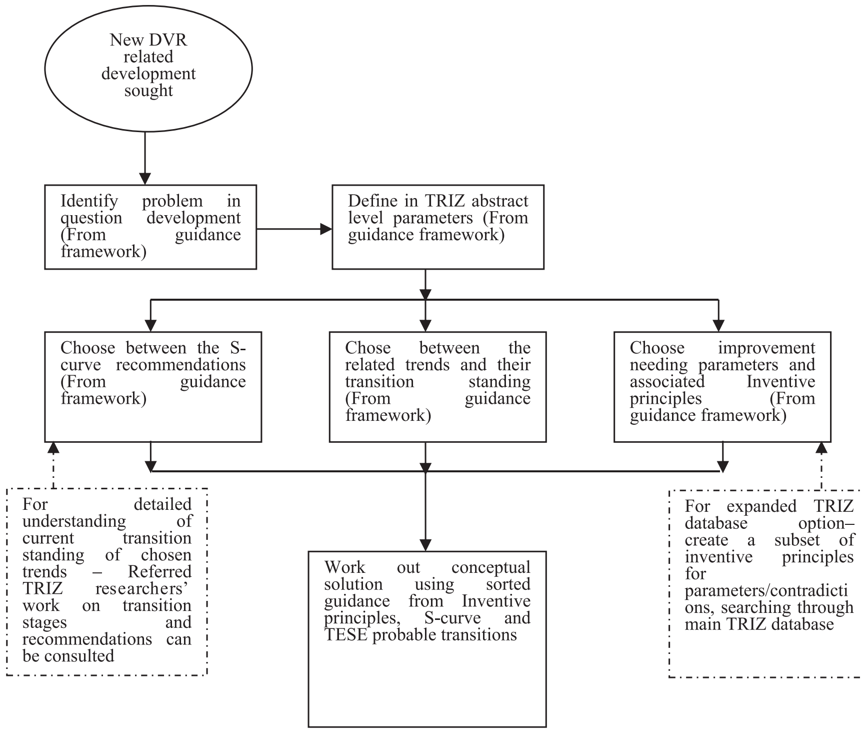


Fig. 7. Proposed methodology for using the guidance framework for DVR.

improvement (Table 4).

Electrical engineers starting with problem hunting may refer to this set of patent knowledge base driven guidelines to focus towards more innovative, out of box, and potential breakthrough solutions with comparatively less solution space and fatigue of random brain storming. The guidelines are proven set of potential successful solution directions based on patent analysis of previously done researches and achieved/successful inventive solutions of similar problems. Electrical engineers can remain more focused on the parameters defined by this guidance chart, following thinking dimensions figured out in this guidance chart and can reach feasible inventive solutions more quickly and confidently. Mapping and building correlation between different parameters and related principles of development in framework above will help electrical engineers move positively towards an innovative and practical solution for DVR advancement and development.

For purpose of utilizing the generated guidance framework, this research recommends stepwise methodology in Fig. 7 to be used. It can help engineers go for a conceptual solution and then problem specific solution, while using guidance framework and their own intuition.

5. Application of developed guidance: Dynamic Voltage Restorer (DVR)

To validate the effectiveness of developed guidance framework, the developed guidance framework was presented to field engineers for test application. The purpose was to assess if the field engineers find this TRIZ based sector specific derivation more relevant, sense making and applicable to their field? Implementation of the guidance framework derived from TRIZ was conducted with diverse level but still not very experienced engineers in particular field. The participants were having the basic knowledge about electronic devices and their functioning principals as electrical engineers but none was introduced to TRIZ before this application. Most of them were not experienced for how to solve an existing problem in already mature technology of DVR. To prove effectiveness of conceptual guidance and generated framework, the aim was to make participant engineers generate a solution with help of conceptual guidance provided by framework while consulting the derived TRIZ framework. As the participants were not introduced to TRIZ, basic level support was provided by the author. Later the feedback of engineers regarding conceptual guidance approach and support is taken and documented to validate the guidance potential and field relatedness of generated framework.

The developed conceptual solution was then presented to all three participants for individual technical solution generation. All three respondent engineers were provided basic one to one assistance over TRIZ abstract level terminologies and field linkage built in generated frameworks and conceptual solution. They were asked to look through the developed guidance and conceptual solution presented. Then they are expected to produce a DVR based electrical sag solution as per their own perception, knowledge and intuition aided with conceptual directions provided. All three produced different solutions as per their own knowledge aided by conceptual directions provided by DVR guidance framework results. Afterwards, the participants were inquired with a questionnaire about their experience with concept of getting guidance at conceptual level and their usage of TRIZ based conceptual guidance. Feedback of all three respondent engineers for questionnaire was summarized and is presented as quantitative analysis summary tables of frequency distribution as in Table 5.

The summary of respondent's feedback shows the positive support for generated guidance framework and research concept of conceptual guidance generation for electrical solutions. From feedback summary it is noted that: 100% of the respondents agreed that the generated framework made them understand TRIZ terminologies better, more related and applicable to their field, as compared with a glance on generic TRIZ database. While 66.7% respondents found the process of deriving guidance from framework systematic, 33.3% participants did not find it very systematic. For support towards thinking process of solution hunting, 100% of the respondents' feedback is positive. Also for support process being less random and more focused with thinking support provided, 100% respondents agreed positively. While 66.7% participants agreed that thinking process support and guidance made them more confident while moving towards a solution, 33.3% did not feel confidence boost because of this guidance. For TRIZ making

Table 5.
Frequency distribution table of feedback.

Sr. No.	Items	Options	Frequency	%
1	Did TRIZ terminologies made a technically supportive sense to you at first glance of TRIZ database?	YES NO	0 3	0 100.0
2	Did TRIZ terminologies made better sense to you after DVR guidance framework presented to you?	YES NO	3 0	100.0 0
3	Did the developed framework made it easy for you to understand guidance directions generated from TRIZ knowledgebase	YES NO	3 0	100.0 0
4	Did the conceptual guidance based directions made you think a solution more systematically?	YES NO	2 1	66.7 33.3
5	Did probable directions for solution finding support your thinking process?	YES NO	3 0	100.0 0
6	Did process of finding a solution became less random and more focused with directional guidance?	YES NO	3 0	100.0 0
7	Did provided guidance made you reach the solution independently?	YES NO	0 3	0 100.0
8	Did it need some background knowledge from you for particular field?	YES NO	3 0	100.0 0
9	Did conceptual guidance match your knowledge and understanding of your own approach towards DVR solution?	YES NO	2 1	66.7 33.3
10	Did the generated guidance support you at conceptual stage of solution?	YES NO	3 0	100.0 0
11	Did generated guidance support you at detailed design stage including specifications and parameters?	YES NO	0 3	0 100.0
12	While working towards a solution aided by conceptual direction gave you more confidence for working out a not so familiar solution for you?	YES NO	2 1	66.7 33.3
13	You felt the difference between your own approach for electrical devices and directions from TRIZ based conceptual solution?	YES NO	1 2	33.3 66.7
14	Do you agree that approach of conceptual directions helped in reaching a solution more smoothly and quickly?	YES NO	3 0	100.0 0
15	Did TRIZ based guidance help in generating solution ideas?	YES NO	3 0	100.0 0

participants reach solutions independently without any prior knowledge of the field, 100% of respondents disagreed and positively replied for need of some prior knowledge in field. For stage of guidance during solution hunting process, 100% agreed that TRIZ supported the process at conceptual design stage but not at detailed design stage. For inquiry regarding, whether TRIZ and generated guidance actually made them feel guided, directed and helped in solution hunting process while making it quick to reach a solution, 100% participants replied positive. Participants agreed in general, that TRIZ based conceptual solution and directions provided support for their thinking process towards reaching a technical solution. Although, the thinking process support again varied with difference of knowledge level in particular field. Where less experienced felt totally dependent and the most experienced felt partially guided for betterment. The overall feedback of participants supported the research aims and validated the concept. It re-affirms that TRIZ does provide strong solution thinking support for electrical engineers and making TRIZ look more applicable to a field by sector specific framework generation does reduce the enigmatic feeling in its usage.

For analyzing the correlation between different chosen inquiry items, strong correlations are found between TRIZ aided guidance with prior basic knowledge of electrical engineering of participants regarding their approach and solution thinking. It supports the concept of using TRIZ for electrical engineering solutions with sector specific guidance generation, as this way it does show relatedness with electrical engineering principals and solutions. Hence, it is making more sense to engineers to seek help from TRIZ knowledgebase with sector specific guidance frameworks.

5.1. Case process execution example

To present the working by field engineers, one of the three respondents work is presented here in more details. Two out of three actually produced some kind of functioning (simulation) solution circuitry based on guidance framework directions. The solution hunting process presented here is from respondent with average skills in DVR and SAG solutions. The process followed recommended stepwise methodological process presented in Fig. 7.

The worked out details are kept to minimal for conciseness of this documentation. The considered guidance chart (Table 4**)**, was presented to engineers for bringing a practical and effective solution to (DVR) response time for SAG event. Using the developed TRIZ based guidance; most probable conceptual solution was formed after discussion with Engineers. After reaching a conceptual solution, technical solution was developed with 'directed brainstorming' on conceptual guidance achieved. Obtained results were a successful solution with very quick response to SAG event. For purpose of reporting, the research is divided in two parts. This part-1 presents real-time SAG detection solution and second has shown a result for SAG response."

By considering guidelines derived from analysis for probable solution direction, an accumulative conceptual solution approach was derived based on following points:

Inventive principles: Intermediary, before hand cushioning, cheap short living objects, copying.

Resources: Fast digital technologies available in market (Buffer etc).

S-curve: Switching principle of action for DVR-SAG detection point.

TESE: Feedback/Fwd control, action coordination.

From above directions, further directed brainstorming was made along with field engineers over conceptual directions provided by analysis. This directed brainstorming resulted in the conceptual solution for detection part as: "Holding I/P by an intermediary cheap object, to act as a cushion before I/P voltage enters the load, and making SAG detection across that intermediary object (before the load point). Using concept of copying (sample signal), a comparison at beforehand cushioning will detect SAG and fast resources (fast electronic devices) may respond immediately before SAG enters load. In case of SAG detection, any delay is removed/bypassed and corrective voltage (backup signal generator) is supplied to load. This virtually gives ideal output "Real-time response time for SAG detection at load point". A schematic circuit diagram for built solution is shown in two parts. First part shows detection schematic circuit and simulated results for detection (Fig. 8). Second part shows schematic circuit for

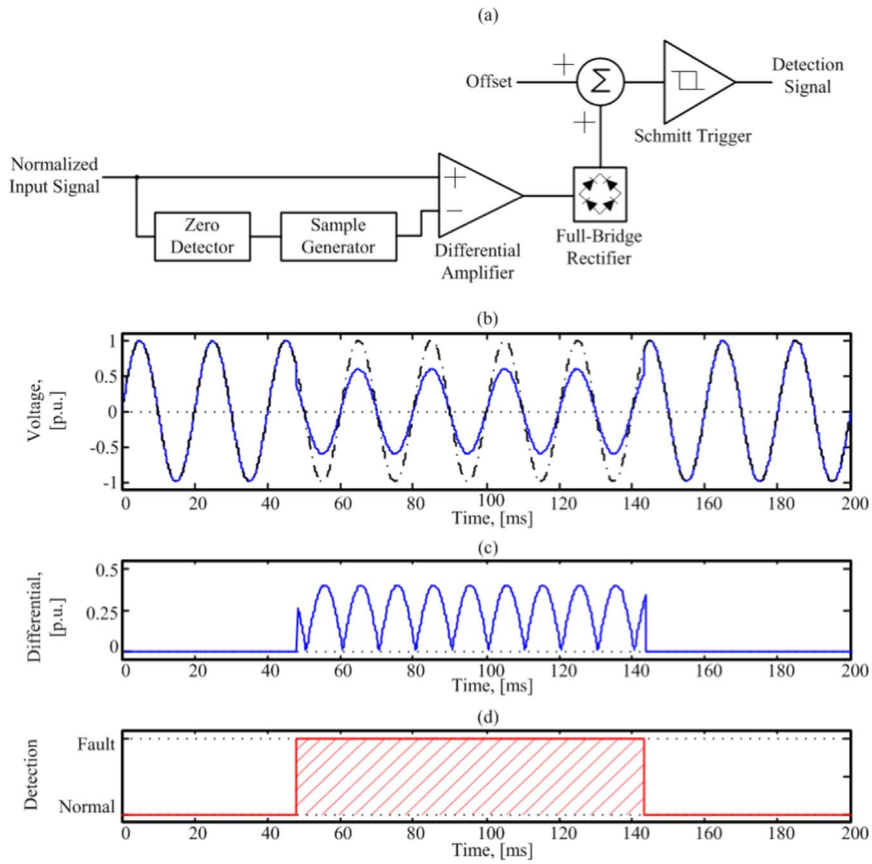


Fig. 8. Schematic diagram for SAG detection solution (Fig. 7a), MATLAB output for detection across the intermediary circuit introduced (7b, 7c, 7d).

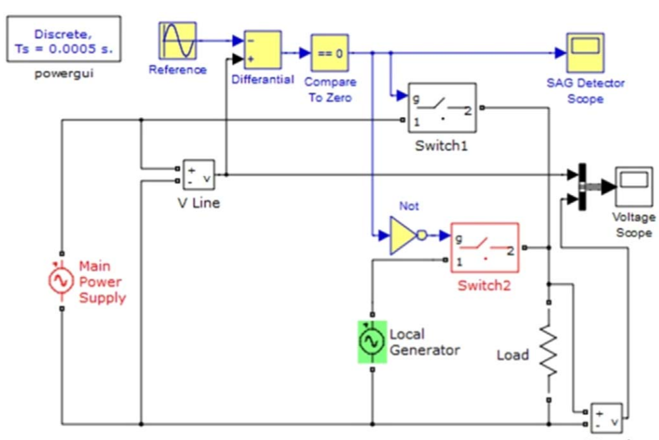


Fig. 9. Schematic diagram for SAG detection and response solution.

complete detection and corrective voltage insertion (Fig. 9). Fig. 10 shows simulated waveform for SAG correction response by the designed solution.

The results confirm that using conceptual directions by DVR-TRIZ analysis (Table 3), directed brainstorming along with professional engineers provided a viable way to detect SAG and provide very fast response to that. This shows capability of TRIZ based guidance worked out for DVR devices (sector specific generic guidance).

6. Conclusions

The research results show achievement of successful conceptual solution which guided participants to probable solutions. Following directions from sector specific TRIZ guidance for DVR, engineers worked out solutions in accordance with their personal knowledge, TRIZ support and self-intuition. The feedback from participants positively supported the idea of sector specific TRIZ framework generation to achieve better understanding of TRIZ for field professionals. The derived guidance framework, including field specific parameters, made field engineers feel that TRIZ is related, lesser complex and applicable to their field. Also that in field of “Electrical Engineering”, where TRIZ application has been documented very less, TRIZ based framework practically supported the thinking process of engineers for generating directions and idea of solution at conceptual design stage. The electrical engineers successfully applied TRIZ principles for their solution hunting purpose and guidance deriving process was rather systematic from generated framework. This proves the strength of approach taken as “TRIZ based sector specific guidance frameworks” for making TRIZ look more simple, related and applicable. In also affirms capability of TRIZ methodology to address problems in electrical engineering domain.

Acknowledgements

This work is conducted at and supported by CAPER, Faculty of Engineering, University Putra Malaysia under UPM Geran Putra grant number 9417300.

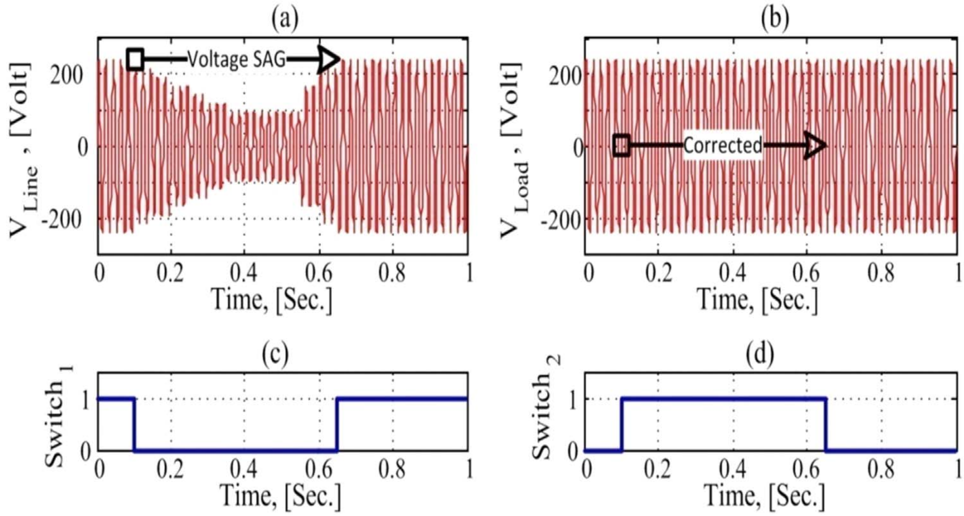


Fig. 10. SAG correction response of designed solution – MATLAB simulation results.

References

[1] Albers A, Wagner D, Kern L, Höfler T. Adaption of the TRIZ method to the development of electric energy storage systems. Procedia CIRP 2014;21(3):509–14. http://dx.doi.org/10.1016/j.procir.2014.02.060.

[2] Huang Z. Design-for-reliability, Starting from conceptual design [PhD Dissertation]. USA: USC Graduate School, University Of Southern California; 2010.

[3] S. Ikenokov MyTRIZ workshop handout notes (Training Manual). MyTRIZ workshop, Malaysia: UniTen, Nov; 2011.

[4] Ilevbare IM, Probert D, Phaal R. A review of TRIZ, and its benefits and challenges in practice. Technovation 2013;33(2–3):30–7. http://dx.doi.org/10.1016/j.technovation.2012.11.003.

[5] K.H. Chai, C. Yeo Overcoming energy efficiency barriers through systems approach—A conceptual framework. Energy Policy, 46 (July), 460–472, ISSN 0301–4215, http://dx.doi.org/10.1016/j.enpol.2012.04.012; 2012.

[6] P Livotov TRIZ and innovation management. Innovator 08/2008, ISSN 1866–4180. Available from: /⟨http://www.triz.it/triz_papers/2008%20TRIZ%20and%20Innovation%20Management.pdfS⟩ [accessed 10.12.14]; 2008.

[7] Luna D, Nadeau JP, Jannot Y. Solar timber kilns: state of the art and foreseeable developments. Renew Sustain Energy Rev 2009;13(6–7):1446–55. http://dx.doi.org/10.1016/j.rser.2008.08.017.

[8] Mann D. Hands on systematic innovation. Belgium: Creax press; 2002, [ISBN 90-77071-02-4].

[9] Mann D. Systematic (Software) innovation. UK: IFR Press; 2008, [ISBN - 978-1-906769-01-7].

[10] Mansoor M, Mariun N, Ismail N, Wahab NIA. A guidance chart for most probable solution directions in sustainable energy developments. Renew Sustain Energy Rev 2013;24:306–13. http://dx.doi.org/10.1016/j.rser.2013.03.037.

[11] Nikolić V, Sajjadi S, Petković D, Shamshirband S, Ćojbašić Z, Por LY. Design and state of art of innovative wind turbine systems. Renew Sustain Energy Rev 2016;61:258–65. http://dx.doi.org/10.1016/j.rser.2016.03.052.

[12] Padmanabhan KK. Study on increasing wind power in buildings using TRIZ Tool in urban areas. Energy Build 2013;61:344–8. http://dx.doi.org/10.1016/j.enbuild.2012.11.038.

[13] San YT, Jin YT, Li SC. TRIZ: systematic Innovation in manufacturing. Malaysia: Firstfruits Publishers; 2011, [ISBN-13: 978-9838040266].

[14] Y.T. San TRIZ Level-2 workshop handout notes (Training manual). TRIZ Level-2 Workshop, Malaysia: KDU, April; 2012.

[15] Yu-Shan Chang YS, Chien YH, Yu KC, Chu YH, Chen MY. Effect of TRIZ on the creativity of engineering students. Think Skills Creat 2016;19:112–22. http://dx.doi.org/10.1016/j.tsc.2015.10.003.