EPRI | ELECTRIC POWER RESEARCH INSTITUTE

TRANSMISSION AND SUBSTATIONS RESEARCH ACTION PLAN

TRANSFORMERS

Managing fleets of aging power transformers is one of the most critical issues facing today's substation managers and engineers. EPRI transformer R&D helps utilities anticipate and prevent transformer failures and extend transformer life by applying new knowledge and technologies to improve inspection, condition assessment, and risk-based asset management.

About Action Plans

Action plans are the Transmission and Substations Area's response to the area Roadmap, and aim to close the gaps and attain the intended future states identified in the roadmap. Action plans serve as multiyear research plans bringing specificity and focus to the roadmap by describing R&D tasks that address area-specific gaps and produce usable results. Each task description maps back to research objectives and identifies future states, specific gaps, the current phase of research, and planned deliverables upon completion. Task schedules and progress are displayed in six-year timelines.

A description of research phases is provided on pages 14-15.

Future States and Gaps

The R&D under way addresses a set of Future States, which are described in detail in the Transmission & Substations Roadmap. Key gaps for transformers are summarized for each future state.

Future State 1: New Components and Materials

Novel transformer fluids and advanced components incorporating new materials promise improved performance, but knowledge gaps must be addressed before utilities can to apply them with confidence. Specific gaps include:

- Field experience and best practices to select, specify and apply advanced insulating fluids such as natural esters and nanofluids
- Evaluation of devices for blocking geomagnetically induced currents (GICs) in transformers to understand performance, efficacy, and system impacts
- Modeling of GIC effects on transformers to support future robust designs
- Understanding of electromagnetic pulse effects on transformers and application of new components and materials for hardening
- Field experience with prototype Recovery Transformers designed to support rapid restoration of power following a disabling high impact low frequency event

Future State 2: Improved Design and Construction

Utilities need vetted design and construction tools and techniques. Specific gaps include:

- Effective design review tools that enable utilities to identify and correct potential design issues and manufacturing flaws early in the development process, and incorporate desired features and capabilities
- Improved condition monitoring to provide data on performance and degradation and failure mechanisms to support improved designs
- Tracking of transformer fleet performance to identify emerging issues and manufacturing flaws with new transformers and to assess performance of aging units
- Knowledge of GIC effects on transformers, efficacy of blocking devices and how to include GIC issues when specifying new transformers

Future State 3: Effective Field Practices

Field personnel need practical tools and techniques for transformer inspection and maintenance. Gaps include:

- Improved capture and transfer of expert knowledge
- Better tools and techniques for on-line, continuous oil processing
- Field experience and guidance on rapid restoration of power using recovery transformers following a high impact low frequency event
- Understanding the impacts on transformers from highly variable and harmonic-rich generation sources
- Industry vetted transformer ratings tools

Future State 4: Effective Inspection, Assessment and Maintenance

Utilities need advanced tools and methods to assess transformer condition and remaining life to support maintenance and replacement decisions. Gaps include:

- Vetted guidance on inspection, assessment and maintenance tools and practices
- Improved maintenance techniques to extend transformer life and reduce maintenance costs
- Safe, fast and effective internal inspections
- Continuous online fluid quality management to maximize transformer service life

Future State 5: Condition Monitoring and Automation

Effective condition monitoring supports failure prevention, transformer life extension, and informed asset management decision making. Gaps include:

- Cost-effective sensors for improved fleet management and decision support
- Specific guidance on transformer condition monitoring techniques—particularly the large volume of new technologies with minimal field experience
- Effective automated interpretation of transformer condition data to allow efficient fleet-wide assessment.
- Secure, standards-based communications infrastructure for sensors
- Effective visualization tools that address all stakeholder needs
- Better tools to assess transformer and component condition and support optimal asset utilization

Future State 6: Asset Management

Comprehensive information on transformer condition and advanced risk-based analytical techniques will enable utilities to identify at-risk units to optimize maintenance, increase reliability, and support capital planning decisions. Gaps include:

- Improved knowledge, algorithms, tools and methodologies to implement fleet management analytics that optimize maintenance, increase reliability, and support capital planning
- Meaningful, defensible metrics and algorithms to understand the implications of aging transformers and make informed decisions regarding maintenance, repair, and replacement over the entire transformer fleet
- More-detailed and extensive information on dominant failure modes and hazard and failure rates to support capital planning
- Expanded knowledge of the performance of different types of transformers and vetted data to support asset management strategies for aging substation transformer fleets

R&D Tasks Underway

R&D Task descriptions are presented in the context of the main future state and gaps being addressed, and are grouped into logical categories. The schedule for the tasks is shown in the Action Map below the task descriptions. Task phases are represented by number; a key is provided on page 15.

Effective Asset Management

Power Transformer Expert System (PTX) for Condition Assessment

PTX is a software implementation of the EPRI analytics-based intelligent fleet methodology. It will incorporate advanced algorithms and performance data to enable a holistic approach to transformer fleet management that addresses capital planning, operations and maintenance. Future research includes further software development and field testing, leading to commercialization in 2018.

Future States: *Condition Monitoring and Automation, Asset Management*

Gaps Addressed: *Effective automated interpretation of transformer condition data that would allow for efficient fleet-wide assessment. Improved knowledge, algorithms, tools and methodologies to implement fleet management analytics that optimize maintenance, increase reliability, and support capital planning.*

Current Phase: *Updating Subject Matter Information*

Deliverable Type: *Software*

Project: *37.111*

EPRI Fleet Management Tool Demonstration and Application

EPRI's analytics-based intelligent fleet management methodology ranks transformers based on their operating environment and operating history, weighing factors such as thermal life consumption, lightning exposure, short-circuit magnitude and duration, insulation oil test results, and connected load criticality. The ranking enables utilities to scan transformer fleets and identify at-risk units for detailed testing and analysis—a far more cost-effective approach than blanket inspections of an entire fleet. This ongoing task will perform field demonstrations of fleet management software and incorporate updates and new features.

Future States: *Asset Management*

Gap Addressed: *Improved knowledge, algorithms, tools, and methodologies to implement fleet management analytics that optimize maintenance, increase reliability, and support capital planning.*

Current Phase: *Development*

Deliverable Type: *Software*

Project: *37.111*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Power Transformer Expert System (PTX) for Condition Assessment	*3.1, 4.2, 5.6*	*3.1, 4.2, 5.6*	*3.1, 4.2, 5.6*	*3.1, 4.2, 5.6*	*3.1, 4.2, 5.6*	*5.7*
EPRI Fleet Management Tool Demonstration and Application	*3.3, 4.3*	*3.3, 4.3*	*3.3, 4.3*	*3.3, 4.3*	*3.3, 4.3*	*3.3, 4.3*

Effective Asset Management *(cont.)*

Bushing and Load Tap Changer Analytics

The research is developing analytics for a condition index that uses readily available data for tap changers and bushings in order to provide a complete transformer condition assessment. The scope of the work includes development, testing, and application of tap changer and bushing condition indices. The final results will be packaged within the Power Transformer Expert System (PTX) for Condition Assessment.

Future State: *Asset Management*

Gaps Addressed: *Improved knowledge, algorithms, tools and methodologies to implement fleet management analytics that optimize maintenance, increase reliability, and support capital planning.*

Current Phase: *Development*

Deliverable Type: *Software*

Project: *37.111*

Industry-wide Database (IDB) for Transformers

The IDB captures transformer operating and failure data on many types of power transformers. It enables statistically valid analysis to better determine equipment failure rates, provide early identification of at-risk units, and identify best practices for maintenance and specification. Analysis yields insights about transformer historical performance and supports fleet management research tools such as PTX. The IDB is an ongoing development and the insights, underlying methodology, approach, and findings continue to be fine-tuned and enhanced as new data sets are added and existing data reviewed.

Future State: *Asset Management*

Gap Addressed: *Expanded knowledge of the performance of different types of transformers and vetted data to support asset management strategies for aging substation transformer fleets.*

Current Phase: *Development*

Deliverable Type: *Industry Database*

Project: *37.112*

Industry-wide Database for Bushings and Load Tap Changers

This task will develop the data model and template for a bushing and load tap changer failure database. The first step will be to institute and begin populating the database with utility historical data, followed by solicitation of data from other utilities. The database will be modeled on the existing Power Transformer Industry-wide Database.

Future State: *Asset Management*

Gap Addressed: *More-detailed and extensive information on dominant failure modes and hazard and failure rates to support capital planning.*

Current Phase: *Scope the Problem*

Deliverable Type: *Industry Database*

Project: *37.112*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Bushing and Load Tap Changer Analytics	*3.1, 4.2, 5.6*	*3.1, 4.2, 5.6*	*3.1, 4.2, 5.6*			
Industry-wide Database Transformers	*6.4*	*6.4*	*6.4*	*6.4*	*6.4*	*6.4*
Industry-wide Database for Bushings and Load Tap Changers	*6.4*	*6.4*	*6.4*	*6.4*	*6.4*	*6.4*

Life Extension and Assessment

Transformer Life Extension: Membrane Technologies for Lifelong Oil Filtration

EPRI research has developed an advanced membrane technology solution to perform continuous online filtration of oxygen and moisture to extend transformer life and reduce maintenance costs. Laboratory testing performed in 2012 confirmed the approach. The next step in 2013 is to engineer a robust field-ready prototype and explore techniques to avoid losing the Dissolved Gas Analysis (DGA) information from the oil. This progress will set the stage for field trials in 2014. Parallel tests will also be conducted on EPRI laboratory transformers to accelerate learning. Field test results will lead to application guidance for utilities.

Future State: *Effective Inspection, Assessment and Maintenance*

Gap Addressed: *Need for improved maintenance techniques to extend transformer life and reduce maintenance costs.*

Current Phase: *Verification*

Deliverable Type: *Investigative Results*

Project: *37.101*

Improved Assessment of Remaining Transformer Life: Chemical Markers

Improving the accuracy of transformer life estimates offers significant reliability and financial benefits in managing aging transformer fleets. EPRI research has identified promising new approaches to more accurate life assessment by tracking the behavior of new chemical markers (and marker ratios) in transformer oil. The approaches have worked well in EPRI accelerated-aging laboratory tests. In 2013, field testing in member substations will help validate the results. Parallel laboratory tests will help in the interpretation of the field results. The research will lead to an Application Guide for assessment of transformer end of life.

Future State: *Effective Inspection, Assessment and Maintenance*

Gap Addressed: *Need for improved maintenance techniques to extend transformer life and reduce maintenance costs.*

Current Phase: *Verification*

Deliverable Type: *Investigative Results*

Project: *37.101*

Field Experience with New Insulating Fluids

Natural esters, nanofluids and other advanced insulating fluids offer potential performance improvements for transformer cooling including increased thermal conductivity, nonflammability, and environmental compatibility. Utilities need vetted guidance for specifying and applying these new insulating fluids in transformers. The following tasks are under way:

- Identifying promising new fluids
- Collecting failure data
- Conducting laboratory and field tests to assess performance and develop knowledge for specification and retrofitting guidelines

Future States: *New Components and Materials, Effective Field Practices*

Gap Addressed: *Field experience, lack of tools and best practices to select, specify and apply advanced insulating fluids.*

Current Phase: *Investigation*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Transformer Life Extension: Membrane Technologies for Lifelong Oil Filtration	*3.3*	*2.3, 4.2*	*2.3, 4.2*	*5.3*		
Improved Assessment of Remaining Transformer Life: Chemical Markers	*4.1, 4.2*	*4.1, 4.2*	*4.1, 4.2*	*5.3*		
Field Experience with New Insulating Fluids	*1.2, 2.1*	*2.2, 2.3*	*4.2*	*4.2, 2.3*	*5.3*	

Evaluation of GIC (geomagnetically induced current) Blocking Devices

GICs can impact transformer life and system performance. In this task, EPRI researchers will:

- Illustrate the changes in GIC flows at adjacent transformers when GIC is blocked at one or more transformers in a region
- Evaluate the effectiveness of GIC blocking devices
- Assess potential unintended consequences of blocking devices on insulation coordination, resonance and system protection
- Use the results of the investigation of local transformer impacts of blocking devices to assess the viability of resulting system operating conditions

Future State: *Improved Design and Construction*

Gap Addressed: *Knowledge of GIC effects on transformers, efficacy of blocking devices and how to include GIC issues when specifying new transformers.*

Current Phase: *Investigation*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

GIC Vulnerability Guide and Mitigation

This task will develop an application guide to help utilities assess transformer vulnerability to geomagnetically induced currents. The guide will provide step-by-step instructions to calculate the transformer rise as a function of time for a given GIC input function. The guide will then describe how to analyze the results and help identify needed next steps.

Future States: *Improved Design and Construction*

Gap Addressed: *Knowledge of GIC effects on transformers.*

Current Phase: *Investigation*

Deliverable Type: *Practices and Procedures*

Project: *37.106*

Recovery Transformer: Field Deployment and Assessment

If a high impact low frequency (HILF) event severely damaged a large number of power and GSU transformers, obtaining adequate replacements quickly would present major challenges. To address this need, EPRI and the U.S. Department of Homeland Security has successfully designed, built, and tested three prototype single-phase 345-kV/138-kV Recovery Transformers. The following tasks are under way:

- A one-year intensive equipment data monitoring program to verify the units' performance, followed by commercialization
- Development of a full deployment plan for recovery transformers

Future State: *Improved Design and Construction, Effective Field Practices*

Gap Addressed: *Field experience and guidance on rapid restoration of power using recovery transformers following a high impact low frequency event.*

Current Phase: *Verification*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Evaluation of GIC (geomagnetically induced current) Blocking Devices	*2.2*	*4.3*				
GIC Vulnerability Guide and Mitigation	*2.1*	*2.2*	*5.3*			
Recovery Transformer: Field Deployment and Assessment	*4.3, 5.7*					

Resiliency *(cont.)*

Recovery Transformer: Full Deployment Strategy

As recovery transformer development and demonstration approach completion, EPRI will develop a full deployment strategy to enable the industry to prepare for and rapidly recover from a potential HILF event that damages key transformers. The strategy will encompass:

- Siting of transformer storage facilities
- Identification of vulnerable transformers
- Transportation modes
- Deployment routes
- Guidelines for transportation, installation and energization

Future State: *Effective Field Practices*

Gaps Addressed: *Lack of field experience and guidance for transformer transportation, rapid deployment and installation practices.*

Current Phase: *Development*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

Design, Specification and Operation

Harmonic Rich and Highly Variable Loading Impacts on Transformers

Solar and wind power resources are examples of sources of increased harmonics and highly variable loading whose impact on power transformer operation is not well understood. This task will begin with a literature survey and laboratory testing to define the impacts and proceed to field data gathering and algorithm development. The goal is to provide members with decision-making tools for how to best manage existing transformer assets and how to specify future transformer investments.

Future States: *Effective Field Practices, Improved Design and Construction*

Gaps Addressed: *Understanding the impacts on transformers from highly variable and harmonic-rich generation sources.*

Current Phase: *Scope the Problem*

Deliverable Type: *Software*

Project: *37.106*

Design Review Software Tools

This task supports development of improved design review tools to allow utilities to identify and correct potential design issues and manufacturing flaws early in the development process, minimize problematic components, and incorporate desired features and capabilities such as:

- Specified monitoring points
- Advanced insulation and insulating fluids
- Construction for enhanced shipping and seismic resistance
- Fire and explosion prevention
- Enhanced fluids management

Future State: *Improved Design and Construction*

Gap Addressed: *Effective design review tools that enable utilities to identify and correct potential design issues early in the development process.*

Current Phase: *Scope the Problem*

Deliverable Type: *Software*

Project: *37.101*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Recovery Transformer: Full Deployment Strategy	*2.3*	*5.1*				
Harmonic Rich and Highly Variable Loading Impacts on Transformers		*1.2, 2.6*	*2.3, 4.1, 4.2*	*4.3*	*5.3*	
Design Review Software			*3.1, 3.2*	*3.1, 3.2*	*4.3*	*5.1*

Design, Specification and Operation *(cont.)*

PTLOAD Development and Technology Transfer

EPRI's PTLOAD power transformer loading software provides a proven tool for substation engineers to calculate maximum safe electrical loading of power transformers under a variety of conditions. This task will integrate PTLOAD with other EPRI equipment ratings software to develop a comprehensive Transmission Ratings Workstation (TRW) to perform ratings studies, evaluate and optimize static ratings, perform real-time ratings, determine emergency ratings, and forecast ratings for transformers, other substation equipment, and entire circuits.

Future State: *Effective Field Practices, Condition Monitoring and Automation*

Gap Addressed: *Better tools to assess transformer and component condition and increase asset utilization.*

Current Phase: *Updating Subject Matter*

Deliverable Type: *Software*

Project: *37.101*

Technology Transfer

Power Transformer Guidebook (Copper Book) Technology Transfer

EPRI's Power Transformer Guidebook captures the knowledge of the world's leading transformer experts to provide a comprehensive reference on transformer procurement, operation, maintenance, and life-cycle management. In this ongoing task EPRI will continue to add new material to the reference and transfer knowledge through annual updates, technology transfer sessions, and electronic training media.

Future States: *Effective Field Practices, Effective Inspection, Assessment and Maintenance*

Gap Addressed: *Improved capture and transfer of expert knowledge.*

Current Phase: *Updating Subject Matter*

Deliverable Type: *Reference Guide*

Project: *37.101*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
PTLOAD Development and Technology Transfer	*3.1*	*2.3, 3.3, 3.4*	*2.3, 3.3, 3.4*	*4.3, 3.4*	*4.3, 3.4*	
Power Transformer Guidebook (Copper Book) Technology Transfer	*6.2*	*6.2*	*6.2*	*6.2*	*6.2*	*6.2*

Effective Diagnostics

Application Guide for Emerging Condition Monitoring Techniques

Testing new condition monitoring technologies directly in the field is costly, risky, and time-consuming. EPRI's transformer test bed realistically simulates most field conditions—and collaboratively, safely and effectively gathers performance data against test protocols. The results are presented in an application guide to provide practical assistance to members on the selection, application, and interpretation of these emerging techniques.

Future States: *Effective Field Practices, Effective Inspection, Assessment and Maintenance*

Gap Addressed: *Lack of specific guidance on transformer condition monitoring techniques—particularly the large volume of new technologies with minimal field experience.*

Current Phase: *Scope the Problem*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

Robots for Transformer Inspection: Application Guide

Transformer internal inspections typically require removal of all the oil to allow an inspector to climb into the transformer. This is an expensive, time-consuming, and risky process. EPRI is planning research on miniature robotic cameras that can be safely submerged and steered in the oil—allowing for a faster and safer inspection of a transformer. The research is planned to start in 2014 with laboratory trials in 2015 and field trials in 2016.

Future States: *Effective Field Practices, Effective Inspection, Assessment and Maintenance*

Gap Addressed: *Safe, fast and cost-effective internal inspections.*

Current Phase: *Scope the Problem*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

Bushings Forensic Examination and Condition Monitoring and Evaluation

Based on statistics from various industry sources, the utility industry is concerned about the performance of transformer bushings. The objective of the research tasks is to better understand how system operating conditions, failure modes, and degradation mechanisms affect the performance of power transformer bushings. Proposed research will cover three broad tasks: review and analysis of available data and literature, forensic investigation of failed and service-aged sister bushings, and full-scale testing to validate online condition monitoring.

Future State: *Effective Inspection, Assessment and Maintenance*

Gaps Addressed: *Vetted guidance on inspection, assessment and maintenance practices.*

Current Phase: *Investigation*

Deliverable Type: *Investigative Results*

Project: *Supplemental*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Application Guide for Emerging Condition Monitoring Techniques		*2.1, 2.2*	*2.3, 4.3*	*2.3, 4.3, 5.1*		
Robots for Transformer Inspection: Application Guide		*2.1, 2.2*	*4.2*	*4.2, 5.1*		
Bushings Forensic Examination and Condition Monitoring and Evaluation	*2.6, 2.2*	*2.6, 2.2*	*4.2*	*5.3*		

Effective Diagnostics *(cont.)*

Load Tap Changer Monitoring Guidelines

Condition monitoring of load tap changers enables utilities to determine if degradation is present or maintenance is required without taking oil samples or removing the transformer from service to open the LTC for inspection. However, utilities lack specific guidance for performing LTC condition monitoring, especially for newer LTC designs. In this task EPRI will develop guidelines for load tap changer monitoring, beginning with literature review and laboratory testing leading to field demonstrations publication of guidelines in 2016.

Future State: *Condition Monitoring and Automation*

Gaps Addressed: *Specific, vetted guidance on condition monitoring techniques.*

Current Phase: *Development*

Deliverable Type: *Practices and Procedures*

Project: *Supplemental*

Optical Hydrogen and Acetylene Sensor Development

EPRI has developed robust, low-cost laser-based sensor technologies to detect hydrogen and acetylene in dissolved gas analysis of transformer oil to economically provide new insights into transformer condition and aging. Laboratory testing and hardware development that began in 2012 will continue in parallel with field trials in a substation and in the EPRI Research Transformer, with commercialization slated for 2015.

Future State: *Effective Inspection, Assessment and Maintenance.*

Gap Addressed: *Cost-effective sensors for improved fleet management and decision support.*

Current Phase: *Development*

Deliverable Type: *Hardware*

Project: *37.101*

Online DGA Monitoring and Analysis: Selection and Application Guide

Online dissolved gas analysis commonly provides the first line of defense for transformer condition monitoring. The challenge utilities face is the large volume of new technologies being offered for field trial. Field trials on in-service equipment are often inefficient and costly. EPRI's research transformer allows utilities to collaboratively learn about new online DGA technologies through execution of well-defined test protocols. This research task also extends to larger scale tests on a full-scale transformer in the laboratory and finally to full-scale demonstrations in the field.

Future State: *Condition Monitoring and Automation*

Gap Addressed: *Better tools to assess transformer and component condition and support optimal asset utilization.*

Current Phase: *Development*

Deliverable Type: *Investigative Results*

Project: *37.101*

TASK *(See page 15 for a key to numerical codes)*	***2013***	***2014***	***2015***	***2016***	***2017***	***2018***
Load Tap Changer Monitoring Guidelines		*2.2, 2.3*	*2.2, 2.3*	*5.3*		
Optical Hydrogen and Acetylene Sensor Development (Hydrogen)	*3.3*	*4.2*	*5.7*			
Optical Hydrogen and Acetylene Sensor Development (Acetylene)				*3.3*	*4.2*	*5.7*
Online DGA Monitoring and Analysis: Selection and Application Guide	*2.1,2.2.3*	*2.2.3, 2.3*	*5.3*			

EPRI's Phased Approach to R&D

Research progresses through technology maturity levels from base research to demonstrations and early deployments. EPRI is focusing on applied research and the maturity levels may not be a good match to describe how the work progresses. The Transmission and Substations Area uses a modified approach in which research proceeds through a progression of activities, or phases, to ultimately produce useful knowledge, tools, and methodologies to address technical and business challenges. Not every research effort contains activities of every phase; some efforts may consist of an investigation and the publication of the results completes the effort. In other cases it may be necessary to develop a solution, including possible mitigation technologies, hardware or software and to verify the solution's efficacy through extensive testing and demonstration, as well as to commercialize the developed technology.

The progression of major R&D phases is summarized below. The page at right displays a complete key to phases by number as displayed on the R&D task timelines.

- ***Scope the Problem:*** Define the problem and gaps to be addressed, develop testing protocols, and perform preliminary studies.
- ***Investigation:*** The key research objective, creation of new knowledge, is performed in this phase. It may include performing literature searches, extensive empirical and scientific experiments as studies, simulations, and bench-top and field testing. The objective of this phase is to create the fundamental understanding and focus of the research. Most research includes some form of this phase.
- ***Development:*** Create solutions in the form of hardware, software, or methodologies.
- ***Verification:*** Test and demonstrate the efficacy of the solution and assess its performance in the laboratory and the field. In some instances the research will need to be verified through at scale demonstrations to establish value.
- ***Tech Transfer/Publishing:*** This is an important phase of the research process: transferring the new knowledge to members. It may include delivering research results in writing and through videos, but may also include hands-on instructions and training on how the results can be applied in the day-to-day operations of the member company.
- ***Updating Subject Matter Information:*** Technology in itself has an expected life span and is expanded or replaced by new knowledge and technology. Research results are "living products" and EPRI regularly revises publications, software and databases to reflect recent advancements.

This phased approach imparts structure and direction to the R&D process. It also supports mid-course reviews and possible corrections. A given project's progress and results may be reviewed at the completion of each phase, providing opportunities to alter direction or scope, speed up the research, or in some cases to terminate the effort if review indicates that progressing to the next phase is not technically or economically justified.

Key to Task Phases

Code	Phase Activity
1	Scope the Problem
1.1	Development of Testing and Assessment Protocols
1.2	Problem Definition
1.3	Study
2	Investigation
2.1	Literature Search
2.2	Laboratory Test
2.2.1	Design and Execute Specific Empirical Tests
2.2.2	Accelerated Aging Testing
2.2.3	Product Technology, Effectiveness Assessment
2.3	Analytical Study
2.4	Research Present Processes and Practices
2.5	Prepare Requirements Specifications
2.6	Collect Event/Failure Information
2.7	Develop Basic Understanding
3	Development Phase
3.1	Algorithm and Model Development
3.2	Methodology Development
3.3	Hardware and Software Development
3.4	Update Software/Add New Features

Code	Phase Activity
4	Verification Phase
4.1	Bench Top Verification Test
4.2	Field Test
4.3	Full Scale Demonstrations
4.4	Early Deployment
4.5	Laboratory Test
4.6	Alpha and Beta Version of Software
5	Tech Transfer - Publishing
5.1	Publish Investigation Results
5.2	Provide SME Knowledge
5.3	Produce Guides
5.5	Produce Reference Material
5.6	Produce Engineering Level Software
5.7	Commercialization
5.8	Applying Software with Member
6	Updating Subject Matter Information
6.1	Update Existing Guides and Guidelines
6.2	Update and Republish Color Books
6.3	Software Maintenance
6.4	Add Equipment and Event Information to IDBs and Republish
6.5	Technology Watch

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