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CONTENT

EDITORIAL

We are happy to present the third issue of *PDPU Journal of Energy and Management* with five search papers on different aspects of energy and management. We are happy to update the contributors to the journal as well as the readers of the journal that JEM has completed the formalities for RNI and ISSN registrations. The journal has also been listed by the University Grants Commission (UGC) as an approved Journal.

A Brief of the Five Papers:

Disasters, natural as well as man-made, have become part of human existence. As disasters have a propensity to strike without much forewarnings and leave a trail of misery, they have to be managed effectively with preparations in advance to face them when struck in order to reduce their impact. They also have to be managed immediately after the disaster strikes.

Capt. (Dr.) Sachinkumar N. Bhagat's paper "Community-Based Disaster Management Strategy in India discusses community based approaches to disaster management in all its phases: prevention, mitigation, preparedness, response, and finally recovery. The paper is based on the actual practical experience of working in different aspects of disaster management and would be a very useful toolkit for community leaders, NGOs and others involved in managing disasters.

Maintaining power system security in all possible operating conditions, including contingencies, has become a matter of paramount importance especially in conditions of continuously increasing load demands. Traditional method of static security assessment using load flow involves long and tedious computations. The second paper by Astik Dhandhia, Vivek Panda, and Siddharth Joshi, discusses an alternative Support Vector Machine based Binary classifier for static security assessment of power system.

The third paper "Simulation on MPPT based Solar PV Standalone System" by Siddharth Joshi, Vivek Pandya and Astik Dhandia reports the results of simulations performed in PSIM (R) 9.3.4 software for PV Module with Maximum power point tracking control system in standalone mode.

Increasing demand for fuels in the world has resulted in use of natural gas in its original form and also as mixture of several gases such as Hydrogen Compressed Natural Gas and Liquefied Compressed Natural Gas and other different variants. The paper by Kirti Yadav and Anirbid Sircar discusses about two technologies, one in which the compressed natural gas is blended with the various proportions of hydrogen, and two, where Liquefied Natural Gas is compressed to about 200 bar pressure to produce Liquefied Compressed Natural Gas.

Long run Sustainability of Nuclear Power is the subject matter of the paper by Vipin Shukla, Vivek Pandya and C. Ganguly. Nuclear power has been emerging as a viable carbon-free option to meet the base load requirements in India. As a matter of fact India is planning to have an installed capacity of about 45,000 MWe of nuclear power by 2030. The paper discusses the on-going and the expanding nuclear power programme in India highlighting the challenges of availability of uranium and plutonium for manufacturing nuclear fuels.

We at the editorial office are very happy to present the latest issue of our journal with incisive studies on the various aspects of energy. We would be happy to hear from you. In future, we also plan to incorporate an Idea Exchange section in the Journal.

- C. Gopalkrishnan

PDPU Journal of Energy and Management (JEM) is an International referred peer-reviewed journal. PDPU Journal of Energy and Management welcomes original papers from both academicians and practitioners on experimental energy science and technology (conventional and non-conventional), energy sector related management, business, and organizational issues related to energy and research. Papers, based on theoretical or empirical research or experience, should illustrate the practical applicability and/or policy implications of work described.

The bi-annual journal carries many features including perspectives, conceptual research, empirical research, colloquium, management case, and book reviews. Authors are invited to submit their contribution under any feature.

AIM AND SCOPE

The proposed research journal shall report and focus on identifying new opportunities, challenges, best practices and strategies for global economy on various complementing issues like business & techno-managerial Issues, regulatory & policy matters, marketing issues, financial & accounting issues, operational excellence & management, social & human resource management and capacity building in general and energy sector in specific.

PDPU JEM is a peer reviewed journal and follows a 'double blind' review process. All the papers submitted to PDPU JEM go through a preliminary review at the editorial desk and those considered appropriate are sent to an Editor representing a specialized domain. On recommendation of the concerned Editor, the Article may be rejected or assigned to two reviewers.

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COMMUNITY-BASED DISASTER MANAGEMENT STRATEGY IN INDIA: AN EXPERIENCE SHARING

Sachinkumar N. Bhagat

ABSTRACT: Community participation is the most effective element to achieving sustainability in dealing with natural and man-made disaster risks. Sustainable development and disaster reduction are essential preconditions for each other. Natural disasters severely hamper the progress and achievements of sustainable development while, at the same time, physical infrastructure that we are constructing may itself constitute a source of risk in the event of future disasters. This is particularly true in the case of earthquakes, where the majority of victims are killed by their own collapsing houses. From the perspectives of environmental degradation, human intervention, and security aspects, disaster management is a pressing issue for all of us and should be undertaken on a comprehensive basis. The approach seeks communities at risk to get engaged in all of its phases: prevention, mitigation, preparedness, response, and recovery. In order to build disaster-resilient communities, they need to be empowered first so that community members can cope with the adverse effects of natural hazards. This is the most effective approach to achieving sustainability in dealing with natural disaster risks. Gujarat State Disaster Management Authority is carrying out various community-based programmers to establish disaster prevention as an essential component of sustainable development. Its activities include improvement of the safety levels of core community facilities such as schools; dissemination of best practices in disaster risk management at the community level; and formulation of integrated programmers for sustainable development through disaster risk management programmer initiatives. The paper presents analysis and some findings of those programs which engage communities to deal with disaster risks.

KEYWORDS

Disaster Management, Community-Based, Risk Management

1. INTRODUCTION

The government alone cannot and will not be able to manage and handle all types of disasters with its machinery without active participation by the people of any country, according to a common theory given by policy makers, experts, and professionals. Failures of top-down effective disaster management approach to reduce risks from of disasters land evidence to this notion. As a consequence, numerous scholars and stakeholders feel that it is high time to adopt a new strategy that will involve vulnerable people directly in planning and implementation of mitigation, preparedness, response, and recovery measures. This is because communities are the best judges of their own vulnerability and are capable of making the best decisions regarding their well-being. This philosophy involves local level people, leaders and community to provide necessary services and logistics to the victims during and after the disaster. Such a strategy has been encouraged both in the developed and the developing countries and launched on Community-Based Disaster Management (CBDM) strategy.

1.1 OVERVIEW OF COMMUNITY BASED DISASTER MANAGEMENT

Community-Based Disaster Management (CBDM) initiates a process involving sequential stages that can be operationalized to reduce disaster risk. Processes of CBDM are guided by principles of subsidiarity, economies of scale, equity, heterogeneity, and public accountability. The different stages in CBDM are disaster/vulnerability risk assessment, risk reduction planning, early warning systems, post-disaster relief, and participatory monitoring and evaluation.

CBDM by its very nature demands a decentralized bottoms-up approach with intensive, micro interventions at the local Panchayats, ward or village level with the intention of generating confidence, awareness, knowledge, partnership, and ownership for planning and rolling out local disaster management plans encompassing all levels of disaster management continuum.

Equity and inclusion of marginalized segments of the society and bringing the vulnerable groups to the center stage of planning and implementation of the CBDM have to be prioritized to make the programme participatory and inclusive. Disasters affect the entire community. However, persons with disability, women and children, underprivileged, older persons, and pregnant women need special attention at the programme implementation level. Such rights and human dignity based inclusive ethos created by such programmes will empower communities and display resilience in times of crisis.

Capacity building and training of community volunteers is the mainstay of community-based disaster management since they are the first responders. Considering a large number of stakeholders and community representatives that need to be sensitized and trained, it is important that capacity building and training interventions be meticulously planned for the purpose of CBDM. CBDM should converge with existing mainstream, institutional mechanisms, and social welfare delivery programmes to make it holistic, cost-effective, multi-dimensional and community-centric.

The 73rd and 74th constitutional amendments recognize Panchayati Raj institutions as "institutions of self and government". They were put in place to decentralize and devolve financial and administrative powers through a tiered structure from the district downwards right up to the Gram Sabha level. In the case of urban self-government, devolutionhas to be brought up to the ward level. The paradigm of CBDM is entirely in keeping with this constitutional recognition of the importance of decentralization and devolution of powers and extends it to the arena of disaster management.

These local bodies can be effective instruments in tackling disasters through a variety of mechanisms such as: hazard, vulnerability and capacity assessments, disaster management planning, early warning system, relief distribution, providing shelter to the victims, medical assistance, etc. The elected representatives of these local bodies are the key stakeholders through whom effective participation and ownership by local communities can be achieved in CBDM.

1.2 WHAT IS COMMUNITY BASED DISASTER PREPAREDNESS?

Preparedness to face disasters is required at all levels right from the household to the State Government to minimize the impact of disasters. The Government cannot reach out immediately to each and every household/village at the time of disaster.

The community is the first responder of any disaster and develops some traditional coping mechanisms to reduce their vulnerabilities. Such communities living in a common territory comprise of women, men, elders, students, teachers and children. There can be recognized as RWAs, resettlement colonies, BPL houses, villages, wards, slums, juggle etc. where people of different social and economic background live together. These people are also responsible for their peace, prosperity, and protection. The involvement of the community is the key factor in any disaster preparedness. The participation of the community is vital to sustain the activities of rebuilding the shattered community life. Community-Based Disaster Preparedness is:

- A response mechanism to save life, livelihood, livestock, and assets with available resources within the community, which should

- Lead to multi-pronged development interventions to address the root cause of vulnerability, and to a self-reliant disaster-proof community.

In order to generate preparedness and response within the people, Community Based Disaster Preparedness Plans (CBDP) has to be developed in all the vulnerable areas of Gujarat. A CBDP is a list of activities a community decides to follow to prevent loss of life, livelihoods, and property in case of a disaster. It also identifies well in advance, actions to be taken by individuals in the community so that each one is aware of his/ her responsibilities when an emergency warning is received. The plans involve training to the community to make them aware of disaster preparedness and make them responsible to protect themselves during and post disasters

1.3 WHY IS IT NECESSARY?

In early times there were only natural disasters causing destruction to the human lives, livelihood, and property. But the fast development of physical infrastructure and technological advancement have also raised frequency and types of the disasters. Manmade (fire, chemical fire, bomb blasts, road accidents) and biological disasters (epidemics, SARS) are the unintended consequences of the present era of technology. In fact, the destruction caused by the disasters is almost unrecoverable and unmanageable until a very long time. The reasons for such severe results are unawareness and carelessness in constructing building structures, unplanned use of land, misuse of chemicals and biotechnology etc. For example, the 6.9 richer scale earthquake in Kutch has caused a massive loss of lives, livelihood, and property that is almost unrecoverable. It has been realized that the community as an institution is the most powerful among the entire mechanism of disaster administration. In the event of actual disasters, the community if well aware of the preventive actions and preparedness measures to be undertaken, can substantially reduce the damage caused by disasters. The efforts of the people in taking initiatives in protecting their lives and properties can be seen in areas where the CBDP process has been established.

The purpose of the manual is to aid facilitators from various governmental, nongovernmental and community-based organizations (CBOs) to facilitate and provide support to the community members in preparing their own community/neighborhood/village disaster management plans (CDMPs) For bringing about ownership for sustainability of the process, efforts have to be made to ensure maximum participation of all sections of the community irrespective of class, caste, sex, and occupation.

A brief meeting should be held to sensitize the prominent members of that community to the DRM Program. Gaining support and confidence of respected members of the community is important for community mobilization. Thereafter, meetings can be held in the Community/Neighborhood/Village depending on the convenience and availability of community for preparing CBDP Plan.

1.4 COMPONENTS OF CBDP.

The Components of any CBDP Plan necessarily include:

I. Community Profile: This includes the community characteristics including its physical, administrative, geographic, demographic, socio economic, and infrastructure profile. Its development position and the context upon which disaster will impact the area, should also be included in the profile

II. Resource Inventory: Involves analyzing the local resources available within the community, which can be harnessed and enhanced for disaster preparedness and response. It shall include a listing of trained manpower, livelihood activities, health, education, water, sanitation, electricity, communications, and transport facilities. It shall also include information a local committee task forces and emergency directory.

III. Risk map through Community Maps: This shall include the Open spaces, Medical Facilities, Communication Facilities, Transportation Facilities, Water Facilities, Temporary Shelters, Sanitation Facilities, and Search and Rescue Operation facilities.

IV. Future Mock drill: this is a list of dates when the periodic mock drill in the community will be conducted.

V. Final community plan: a one-page pamphlet detailing out the main CBDP components.

2. PREPARATION AND PROCESS OF COMMUNITY-BASED DISASTER MANAGEMENT PLANS FOR COMMUNITY RESILIENCE.

The logic behind the Community based Disaster Preparedness plans is to involve communities in identifying and mapping their own hazards, vulnerable sections, resources available, and safe evacuation routes. Therefore, the planning process has been divided into three major sections.

• Identification of Community unit and preparation of Community Profile

• Preparation of Community map showing vulnerable areas, resources, and evacuation routes

• Preparation of Taskforces, Committees, and Emergency Response Team

The plan should have made by members of the community irrespective of class, creed, sex and occupational status, supported and facilitated by Community representatives, Local NGOs, Volunteers, and Government officials. The facilitators should have the skills to motivate the community, conduct the meetings and encourage as participatory an approach as possible.

STEP 1:
COLLECTION OF BASIC INFORMATION AND IDENTIFICATION OF A LOGICAL UNIT

Before starting with the planning process the facilitator should get prior idea about few logistics related to population, economic conditions, and area of the target community. This information would be helpful to decide the number of a logical unit for that area. For example, if the community is comprised of a high density of population or large area, then preparing a single plan for the entire community may not be a desirable solution. In such cases, the community can be divided into two or more parts depending upon convenience for implementation. Similarly, if the case is opposite and the community identified is very small, a single plan may be good enough.

STEP 2:
ORGANIZING COMMUNITY MEETING BY INFORMING MOST OF THE COMMUNITY PEOPLE

A meeting should be organized with the community representatives on a convenient date and venue so that most of the community members could be involved in the planning process. Community representatives and plan facilitators should make sure that the target community has prior information about the meeting. The information can be sent through notice circulation, display of notice on notice boards, distributing pamphlets, and announcing in a general body meeting. Gram Sabhas could be convenient vehicles for information dissemination. It would also be preferable to conduct the meetings after 6:00 pm after the work hours, for maximum participation of the villagers.

Points to remember during a presentation to the community:

I. The preliminary presentation to the community should contain the following:

- Disaster (types and occurrence).
- Disasters in Gujarat.
- Comparisons with some examples, e.g. Delhi Vs. Ahmedabad.
- Dos and don’ts for all types of disaster.
- Family preparedness plan.
- Why CBDP is important.
- BDP Processes.

II. Any presentation for the community should keep the following points into account:

- The presentation should be prepared considering the profile of the community.
- List out the major issues concerning the community and highlight the solutions to those issues in your presentation.
- Highlight the results of the household questionnaire in your presentation. If no questionnaire is answered highlight that too.
- Present the issues in an organized manner,
- On the last day of the CBDP, the points presented on the first day should be revised.
- At all times it should be emphasized to the community that it is their plan and they should update it regularly.
- Need for mock drills should be emphasized.

III. Some basic material should be distributed in the community before the CBDP facilitator goes to the community, to build the environment conducive to CBDP Planning, some of which are given in the annexure.

IV. First mock drill within the community should be held with the help of the CBDP facilitator.

V. The CBDP facilitator should also be able to point out the drawbacks and help to remove those drawbacks.

STEP 3:
PREPARATION OF COMMUNITY PROFILE

In any planning process first and foremost step is to collect the baseline information about the community. Population characteristics, Socio-economic characteristics, and Physical characteristics are the important aspects of about the selected area. Such information helps in analyzing socio-economic conditions of the area and enables to figure out the level of vulnerability.

Population characteristics include approximate information about a total number of families. The total population should be divided into, male population, female population, children, and disabled cases further.

Physical Characteristics involves collection of information of the area, land use, soil type, and land holding pattern.

Housing typology includes the type of housing, mode of construction, flatted or single houses etc.

Economic characteristics include major income groups and type of prominent economic activity in which the community is engaged.

STEP 4:
PREPARATION OF COMMUNITY-BASED DISASTER PREPAREDNESS MAP

Steps to be followed for the community-based preparedness mapping, including risk analysis and hazard mapping, resource inventory and resource mapping, and finally identification of safe routes.

In the Risk Analysis and Hazard Mapping, normally The community identifies various hazards on the basis of previous experiences related to earthquakes, cyclones, chemical explosions, fire and any other accidents. Facilitators also collect information about the type disasters, date of occurrence, a frequency of occurrence and destruction caused. Based on the previous experiences of disasters, The community would identify groups of people who are most vulnerable, such as the elders, disabled persons, pregnant women, widows and small children, families living in juggiles, slums and low lying areas. In a few cases cattle and livestock, weak structures, standing crops and livelihood assets should also have to be listed down.

The community also identifies vulnerable locations within their specific area such as juggiles, explosive factories, go-downs, accident-prone areas, and other vulnerable locations. The community should locate and mark all the vulnerable and hazard-prone areas on the community base map.

Next step would be a preparation of resource inventory and resource mapping which will evolve. While identifying resources available. The inventory of resonance would include:

• Open spaces: Parks, sports complexes for temporary shelters, helicopter landing and safe routes;

• Medical Facilities: Number of hospitals, clinics, dispensaries, medicos, equipments and trained manpower for medical assistance in the area and in the neighborhood.

• Communication Facilities: Radios, televisions, telephone exchange, mobiles, public telephone services etc.

• Transportation Facilities: Buses, tempos, cars, trucks, taxies, three wheelers and two wheelers and pucca roads etc.

• Water Facilities: Water storage tanks, overhead tanks, bore wells, hand pump, community water posts, government or private tankers, sources of bottled water and tube wells etc.

• Temporary Shelters: Schools colleges, community halls etc.

• Sanitation Facilities: Power stations, substation, generators, torches and invertors etc. for electricity supply.

• Public toilets, Community bathrooms, solid waste disposal sites and cremation sites etc.

• Search and Rescue Operation facilities: Fair price shops, kerosene depots, CNG depots, cooking gas depot etc. for food and supply purpose and JCB, Crane, Cutters, Bulldozers, RCC Cutters, Ropes, lamps, and ladder etc.

All this information should be marked on the base map where vulnerable areas have been shown. After mapping these resources, the community would decide the shortest and closest ways / safe routes for evacuation during the situation of emergency. After doing the analysis of risk involved and resources available within a community, the facilitators can also raise important caution points and also give important recommendations.

STEP 5:
PREPARATION OF LOCAL COMMITTEES, TASK FORCES, AND EMERGENCY DIRECTORY

The plan has been made for the communities. It would be advisable if the community constitutes its own Community Disaster Management Committee and nominates names of the members. These members would be further responsible to practice the plan and update the plan from time to time. These members would also prepare the task forces which would take actions at the time of disasters and also approve the plan as an implementing plan. These members can be community representatives (preferably), teachers, school or college principals, leaders, social workers or NGO members.

Around 6 to 7 task forces are proposed to be constituted in each community. These taskforces would be related to search and rescue, damage assessment, trauma counseling, first aid, early warning and communication, relief coordination and provision of water and sanitation. Around 3 to 7 people are preferred to be the part of each task force. These members are selected by the community from amongst motivated and responsible volunteers with the relevant skill sets who can implement and supervise the activities as per the plan, For example, members of Community youth clubs, female members of the Community, self-help groups, literate youth of the Community, school teachers, health workers and so on who are nominated by the local community could be the members. Adequate participation from women is an important aspect of the plan. The Standard Operating Procedure (SOP) is also amended as per the requirements.

I. Search and Rescue Team: The objective of the team is to trace and locate people who are physically trapped in the collapsed buildings, houses and on river banks. This team helps these people to move out and transfer them to the safe locations. These people should be 3 to 7 physically and mentally strong men and women, preferably from drivers, swimmers, cutters, and climbers. All members should have basic knowledge of first-aid and should be residents of the target community.

II. Relief Co-ordination Team: The team would be responsible to establish contact with district collector's office control room, civil society organizations, and NGOs for obtaining and in case of distributing relief material such as food, water, medicines, temporary shelters, blankets, household kits, candles and so on. They are also responsible for fair distribution of the relief within the community. This team should comprise of community representatives, social workers, women members and leaders of the community.

III. Early Warning and Communication Team: To ensure that the warning of the impending disaster reaches every single household on time, accurate information is to be provided regularly of any disaster taking place in other areas, Information should flow quickly and reliably upwards to district level and downwards from district to Community Level These team members should be literate, energetic and should communicate confidently and accurately. These people should also have telephone or mobile phone, radio or television and they should read the newspapers regularly and/or trained in the use of HAM radio.

IV. Water and Sanitation: This team is important to make available safe drinking water to the community and livestock. The team should also ensure availability and cleaning of temporary toilets, bathrooms, and temporary shelters. The task force members should be individuals preferably with some knowledge of water-specific public health and sanitation. Women candidates are also preferred in this team.

V. First Aid and Health: The team would be responsible to provide primary health care to injured people until medical assistance is provided to the patient. This group would be comprised of persons who are literate, having health-related knowledge or working in the field of medicine and are respected members of the community. Women members presence in this team, would be highly advantageous.

VI. Trauma Counseling: This team would be responsible to take care of the affected people through counseling so that they could come out from mental pressure arising from the disaster. Social workers, psychologists,psychiatrists, students, and priests can be good councilors for the victims.

VII. Training sessions for the Task Forces: Training plays an important role in disaster mitigation and should be organized for each sector. Duration of training will vary from a few hours in the evening spread over to a week. This depends however on the convenience and availability of task force members and the nature training module. The venue should be accessible for a maximum number of people. A conscious effort would be made to integrate training for peace time activities into the training program.

VIII. Emergency Directory: This is the least but not last important component of the process. The directory would include phone numbers and contact details of district-level administration including District collector/

Deputy Commissioner, Additional District Magistrate, Chief District Medical Officer, Chief Fire Officer, Deputy Commissioner of Police, Deputy Commissioner of Municipal Cooperation, Food and Supply Officer, Transport Authority Officers and District Liaison Officer etc. The details of local NGOs would also be listed down. Besides that, contact details and names of all the committee members, trained manpower, and resource persons would be included in the directory.

All this information would be helpful in preparing a comprehensive approach to hazard specific pre-disaster preparation, during and post-disaster response. The questionnaire would also support in posing questions to the community groups to obtain information on the specific situation.

STEP 6.
CONDUCTING MOCK DRILLS

Mock drill is another important aspect of this plan. Without practice, one would not be able to use these safe routes at the time of emergency. Such kind of mock drills should be organized frequently by the committee members with the help of nearest fire service Station and Civil Defence. During the mock drills, people should practice to come out form their buildings and houses within 3-4 minutes to the open spaces identified in the community maps. Taskforces should also practice conducting their primary activities of conducting Search and Rescue, Damage Assessment and Early Warning System, First Aid and Trauma Counselling etc. After collecting all these information, a community plan would be written by the experts. Copy of the detailed plan should be made available to the community representatives, NGOs and all these connected in the district level administration.

3. CONCLUSION

Past experiences in the Gujarat (India) affirm the effectiveness of involving communities in disaster preparedness and mitigation. However, local communities cannot reduce all vulnerabilities on their own. While communities have built on local coping strategies and capacities to reduce some vulnerabilities, many necessary structural mitigation measures involve big capital outlay. More important, vulnerability is also a complex web of conditions, factors, and processes, which can only be reduced through complementary and concerted action among multiple-stakeholders from various disciplines and levels of the disaster management and development planning system.

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STATIC SECURITY ASSESSMENT USING BINARY-CLASS SUPPORT VECTOR MACHINE

Astik Dhandhia, Vivek Pandya and Siddharth Joshi

ABSTRACT: In the present day due to the increase of load demands day by day, Power system becomes complex, and it is operating near its bus voltage regulation limits and thermal capacity limits of the lines. So, it is vital to maintaining power system security for every possible operating condition including contingencies. The traditional method of static security assessment using load flow requires long computation time and complex calculations. This paper presents a Support Vector Machine based Binary-classifier for static security assessment of the power system. The proposed classifier classifies power system operating condition into secure and insecure, based on the computation of the Composite Security Index (CSI). Thermal limit of the transmission lines is chosen on the base of load ability limit of the short, medium and long transmission line. Single ranking and Correlation Coefficient Method is used for feature selection. The proposed approach is implemented, and classification accuracy is verified on IEEE 14 and 30 bus systems.

KEYWORDS

Static Security, Support Vector Machine, Feature Selection, Composite Security Index

1. INTRODUCTION

Power system mainly deals with generation, transmission, and distribution of electrical power. Due to increasing of day to day requirement of power one has to increase generation of electrical power. At the same time, there is a need for enough structure for distribution and transmission networks. All generating stations, transmission lines, and distribution lines are working in overloaded condition due to limited structure and limited sources of electrical power generation. Power system security includes the process of keeping the system operating when disturbances occur in the power system. Disturbances in the power system are due to outages of transmission lines, Generators, and Transformers, etc.

Power system security analysis is carried out in control center, and it is divided into mainly three categories, viz., power system monitoring, contingency analysis, and security constrained optimal power flow (Wood&Wollenberg, 2012). A power system security assessment is the steps performed to determine whether the system is safe from serious outages and to what extent it is safe in its operation (Kalyani&Swarup, 2009).

The concepts of power system security and stability are interrelated in power systems. There are three modes of the stability on operational point of view, viz., steady-state stability, which is related to the system steady-state condition following any small disturbance, transient stability, which discusses with the capacity of the system to remain in synchronism when a large disturbance occurs, and dynamic stability, which concerns with the system's long-term response. Based on the three modes of stability System security can be classified into the three modes. The method of security is classified based on the specific outages, variables used for analysis and time after the outage. Nevertheless, after analyzing the condition, the system can be classified as Steady state or transient or dynamic secure if it is stable for every outage in the contingency list defined for each mode respectively. Otherwise, it is called as insecure (Costa&Munro, 1984).

Static security is the ability of a power system to reach a steady state operating point without violating the system operating limits following a contingency (Mohammad&Yaoya, 2003). Evaluation of Static security is called as static security assessment. Traditional methods used for contingency analysis is time-consuming. Full AC load flow is utilized for each outage in traditional contingency analysis. The complete procedure required for contingency analysis requires lots of time and gives many results. The traditional methods are not suitable for real-time applications due to varying nature of the power system (Pang&Koivo, 1973).The engineer working in the control center requires enough time to take the control action. If enough time is not given to the engineer cascade tripping of the several types of equipment may occur. The main requirement of the consumer from the utility is the availability of the power as and when required. So, the growth of the country or the society depends on the reliability and quality of the power.

Several Artificial Intelligence techniques were used in security assessment since last four decades. Artificial intelligence techniques like the Self-Organization feature map (Niebur&Germond, 1992; Swarup&Corthis, 2002), and Multi-layered feed forward network (Swarup&Corthis, 2002), (Saeth&Khairuddin, 2008) have been applied to the problem of static security assessment. Some of the literature also reported the use of Radial Basis Function Neural Network (Refaee et al.,1999; Jain et al. ,2003), a Genetic-Based Neural Networks (Aini, 2001) and Query-Based learning approach in Artificial Neural Network (Huang, 2001). Techniques other than Artificial Neural Network (ANN) used in the static security assessment are problem dependent. Neural Networks are good in interpolation but not so good in the extrapolation, which reduces its generalization ability (Kalyani&Swarup, 2001). To overcome the disadvantages of ANN the researchers started use of Support Vector Machine (SVM) based classifier for static security assessment (Kalyani&Swarup, 2011). In the available literature, Static Security states were classified based on either by Equality and Non-equality constraints or using Performance Index. In most of the literature, the crucial part is to decide weighting factor to calculate Security Index. Selection of weighting factor depends on knowledge and experience of the concerned person associated with the particular system. The wrong choice of weighting factor leads to misclassification of security states. Static Security Index was used in the classification of static security states (Kalyani&Swarup, 2011)in which weighting factor is assumed on the base of knowledge and experience. Composite Security Index (CSI) is defined in (Sunitha&Kumar, 2011) and builds on the concept of a hyper-ellipse inscribed within the hyper-box. The main advantage of CSI is that in the calculation there is no need to select proper value of weighting factor. In the most of the literature found, thermal limits of the transmission lines are assumed in the Static Security assessment.

The main work presented in this article are (Wood&Wollenberg, 2012) Composite Security Index is used instead of Performance index with weighting factors. (Kalyani&Swarup, 2013) The thermal limits of the transmission lines are calculated and considered on the base of load ability of the transmission line for short, medium and long lines for calculation of CSI. The load ability limits of short, medium and long lines are considered based on surge impedance loading, percentage voltage regulation, and steady-state stability limit's of the lines respectively. The SVM classifier is designed for Binary-class classification. Based on the value of CSI the classifier is intended to classify the state into secure and insecure following Static Security assessment. The proposed SVM classifier is applied to the IEEE 14 and 30 bus systems.

The remaining part of this paper is structured as follows: Static Security Assessment using the composite security index based on the concept of a hyper-ellipse inscribed within the hyper-box is explained in Section 2. The approach utilized for the calculation of the thermal limit of the transmission line is briefly described in Section 3. The design of Static Security Classifier using Pattern Recognition Approach is explained in Section 4. Performance evaluation of the classifier is given in Section 5 and Results, and discussions are presented in Section 6.

2. STATIC SECURITY ASSESSMENT USING COMPOSITE SECURITY INDEX

The composite security index is the combination of the two terms line flow and bus voltage limit violations. Two kinds of limits are defined for bus voltage, and line flows, viz., the security limit and the alarm limit. The security limit is the maximum limit specified for the bus voltages and line flows. The alarm limit represents alarm zone adjacent to the security limit, which gives an indication of nearness to limit violations (Sunitha et al., 2011).The system is said insecure if any bus voltages or line flows violate their security limit. If any bus voltages or line flows violate their alarm limit without violating their security limit, the system is considered to be in the alarm state. If none of the voltages or line flows violates an alarm limit,the system is called secure. This is specified by a value of “0”. The upper and lower alarm limits and security limits of bus voltages are denoted as A_i^u, A_i^l, V_i^u and V_i^l respectively. The normalized upper and lower voltage limit violations above the alarm limits are given in (1):

$$Y_{v,i}^{u} = \frac{[V_i - A_i^u]}{V_i^d} \quad ; if\ V_i > A_i^u$$

$$Y_{v,i}^{u} = 0 \quad ; if\ V_i \le A_i^u$$

$$Y_{v,i}^{l} = \frac{[A_i^l - V_i]}{V_i^d} \quad ; if\ V_i < A_i^l$$

$$Y_{v,i}^{l} = 0 \quad ; if\ V_i \ge A_i^l \qquad (1)$$

Where V_i is the voltage magnitude at bus i. For all upper and lower limit of bus voltages, the normalization factor $D_{v,i}$ is given in (2):

$$Z_{v,i}^{u} = \frac{[V_i^u - A_i^u]}{V_i^d}$$

$$Z_{v,i}^{l} = \frac{[A_i^l - V_i^l]}{V_i^d} \qquad (2)$$

From equation (1) and (2), the value of the ratio (Y/Z) will give a value of "0" if the value of the bus voltage is between lower and upper alarm limit. It is classified as the secure state. If the value of the bus voltage is greater than the upper alarm limit or less than the lower alarm limit, it gives a value (Y/Z) greater than "0". It is classified as the alarm state. If the value of the bus voltage is greater than the upper-security limit or less than the lower security limit, it gives a value (Y/Z) greater than “1”. It is classified as the insecure state.

For line flows, the limit violation vectors and the normalization factor are defined similarly. Since only the maximum limits are necessary to be stated for the power flow through each line, two types of upper limits are given for each line: the alarm limit and the security limit. The security limit is the maximum limit of the power flowthrough the line. The normalized violation vectors for each line j are given in (3):

$$X_{p,j} = \frac{[\,|P_j| - P_{A,j}\,]}{Base\ MVA} \quad ; if\ |P_j| > P_{(A,j)}$$

$$X_{p,j} = 0 \quad ; if\ |P_j| \le P_{(A,j)} \qquad (3)$$

Where $_j$J is the absolute value of the power flow through the line and $P_{A,j}$ is the alarm limit for power flow. The normalization factor for each line is given in (4):

$$Z_{P,j} = \frac{[\,P_{P,j} - P_{A,j}\,]}{Base\ MVA} \qquad (4)$$

Where $P_{P,j}$ is the security limit of the j^{th} transmission line. Here also, the system can be classified with respect to the power flow through the line viz. secure, alarm and insecure based on the value of (Y/Z) vector.

The concept of hyper-ellipse inscribed within the hyper-box is used for constructing the scalar valued composite security index PI_{com} from the violation vectors are given in equation 1, 2, 3 and 4 it is given in (5) as

$$PI_{com} = \left[\sum_i \left(\frac{Y_{v,i}^{u}}{Z_{v,i}^{u}}\right)^{2n} + \sum_i \left(\frac{Y_{v,i}^{l}}{Z_{v,i}^{l}}\right)^{2n} + \sum_j \left(\frac{Y_{p,j}}{Z_{p,j}}\right)^{2n} \right]^{\frac{1}{2n}} \qquad (5)$$

Where "n" is the exponent used in the hyper ellipse equation. The value of "n" is chosen as "2", because the approximation of hyper-box to the hyper-ellipse has not improved beyond "n" = 2 (Sunitha et al., 2011). From the value of the composite security index, the system is classified to be in one of the two states as given in Table 1.

Composite Security Index (CSI)	Class Category
$PI_{com} \le 1$	Secure
$PI_{com} > 1$	Insecure

TABLE 1. Class Categories for Security Assessment

3. CALCULATIONS OF THERMAL LIMIT OF THE TRANSMISSION LINES

In most of the work presented in the literature thermal limit or security limit of the transmission lines are assumed, the thermal limit of the transmission lines is provided by the manufacturer of the transmission line. Thermal limits of the IEEE standard bus systems are not available in the available kinds of literature. Most of the researchers have assumed thermal limits on the base of the experience. Kalyani et al., (2011) assumed thermal limit or MVA limit of system branches as 130% of the base case. Kalyani&Swarup, (2009) and Sekhar et al., (2016) assumed allowable maximum power flow through the transmission line using maximum power transfer equation in which δ is taken as 90^0 (Shekhar&Mohanty, 2016), but according to steady state stability, we can allow the value of δ in between 40^0 to 45^0.

In this work, the thermal limits of the IEEE standard test systems are considered based on loadability limit of the transmission line. The transmission lines of the IEEE standard test systems are classified as short, medium and long lines based on X/R ratio. The loadability limit of the short transmission line is equal to the thermal limits of the line and that is decided on the base of surge impedance loading. The voltage drop limit determines the loadability limit of the medium line. The ratio VR/VS ≥ 0.95 is taken to decide the loadability limit of the medium line. The steady state stability is a limiting factor for the loadability limit for the long transmission line (Duncan&Sharma, 2012). For calculation of loadability limit of the long transmission line, the angle δ is taken as 45^0 in equation 6.

$$P_{max} = \frac{V_i V_j}{X_{ij}} \sin \delta \qquad (6)$$

4. DESIGN OF STATIC SECURITY CLASSIFIER USING PATTERN RECOGNITION APPROACH

A pattern is a pair consists of information or observation and the meaning of the observation. Pattern recognition interprets meaning from observation or information. Pattern recognition is defined as the operation of taking raw data and taking action based on the class of data. Classifying the patterns based on either past knowledge about the system or statistical information is obtained from the patterns. The main aim of applying pattern recognition approach to security assessment is to reduce the online computation time (Kalyani&Swarup, 2011). It can be done at the cost of an extended offline computation. The progression of steps carried out in the design of static security classifier is represented in the form of the flow chart in Figure 1.

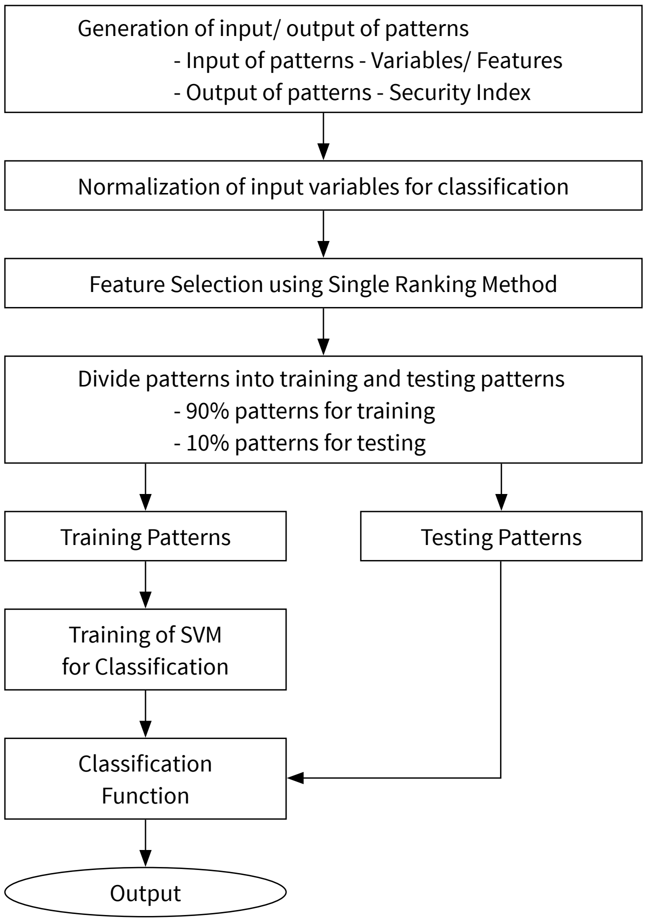

FIGURE 1. Main steps in design of static security classifier

As shown in Figure 1, the design of static security classifier using SVM goes through a series of sequential steps. In upcoming sections, explain the steps and Support Vector Machine used in the classification scheme. The main stages are data generation, normalization, feature selection, classifier design and performance evaluation.

4.1. DATA OR PATTERN GENERATION

The success of any classifier depends on good and wide ranges of the training sets. The training set must represent entire operating states of the power system (Kalyani & Swarup, 2009). This training set can be formed either by collecting past real measurements or by offline studies of the power system. A large number of operating scenarios are generated through offline simulations. Each operating scenario is considered as a pattern. Each pattern consists of power system variables such as bus voltages (V_i), bus angles (δ_i), active and reactive bus loads (P_i and Q_i), active and reactive generations (P_{Gi} and $_GQ$), active and reactive power flows (P_{ij} and Q_{ij}) through the transmission line. Patterns are generated by changing the load on the bunch of the buses from 50% to 150% of the original load arbitrary. Single line contingency is considered for this work.

4.2. NORMALIZATION OF DATA

Normalization of pattern variables is done to improve the performance of the algorithm. The main advantage of normalization in Support Vector Machine is helpful to reduce the effect of the attributes in greater numeric ranges on the attributes of the smaller numeric ranges, and it also reduces numerical difficulties during the calculation. Because kernel values usually depend on the inner products of feature vectors, e.g. the linear kernel and the polynomial kernel, large attribute values might cause numerical problems. The variables in the feature vector are normalized in the range (Wood&Wollenberg, 2012) using the min-max normalization method. It is one of the widely used techniques by most of the researchers for the data scaling process (Kalyani&Swarup, 2011).

4.3. FEATURE SELECTION

The success of any classifier depends on the selected features for the classification. To get complete information about the nature of the power system, the features are selected in high numbers. Therefore, it is important to decide the relatively small number of features unique for classification (Weerasooriya&Sharkawi, 1992). Feature selection is a process of selecting important features from a total number of features. Selected feature will give more useful information than not selected features. Engineering judgments may select features, but occasionally it may lead to rejection of important features.

Single ranking and Correlation Coefficient Method is used for feature selection. The heuristic notion of interclass distance is used to select the important features. The average pair wise distance between the patterns is useful information for the measure of class separability in the region concerning the particular variable. The index F_i provides a measure of this class separation concerning the i^{th} variables.

$$F_i = \left| \frac{m_i^{(s)} - m_i^{(I)}}{\sigma_i^{(S)2} - \sigma_i^{(I)2}} \right| 1 \leq i \leq 1 \qquad (3)$$

Where,

$$m_i^{(S)} = \frac{1}{N^{(S)}} \sum_{j=1}^{N(S)} X_{ij}^{(S)}$$

$$m_i^{(S)} = \frac{1}{N^{(S)}} \sum_{j=1}^{N(S)} X_{ij}^{(S)}$$

$$\sigma_i^{(S)2} = \frac{1}{N^{(S)}} \sum_{j=1}^{N(S)} \{ X_{ij}^{(S)} - m_i^{(S)} \}^2$$

$$\sigma_i^{(I)} = \frac{1}{N^{(I)}} \sum_{j=1}^{N(I)} \{ X_{ij}^{(I)} - m_i^{(I)} \}^2$$

Where, $m_i^{(.)}$ and $\sigma_i^{(.)2}$ are mean and variance if variable corresponding to class (.). The superscript (S) stands for 'secure' while (I) stands for 'insecure'. $N^{(S)}$ and $N^{(I)}$ indicate the number of secure and insecure patterns that form the training set $\{N = N^{(S)} + N^{(I)}\}$. Variables with higher values of F suggest more information about class separability than others. Therefore classification can be based on selected variables which will be referred to as features.

The correlation coefficient between the i^{th} and the j^{th} variable is defined as:

$$C_{Cij} = \frac{E\{y_i y_j\} - E\{y_i\}E\{y_j\}}{\sigma_i \sigma_j} \quad i,j = 1,2,\ldots,n$$

Where,

$$E\{y_i y_j\} = \frac{1}{N} \sum_{k=1}^{N} y_{ik} y_{jk}$$

$$E\{y_i\} = \frac{1}{N} \sum_{k=1}^{N} y_{ik}$$

$$\sigma_i^2 = \frac{1}{N} \sum_{k=1}^{N} (y_{ik} - E\{y_i\})^2$$

The following steps for feature selection:

1. Calculate F_i for all i such that $0 \leq i \leq n$.
2. Arrange variables according to the descending order of F_i.
3. Go to the first variable with highest F_i value.
4. Calculate correlation coefficients if all remaining variables with respect to this variable.
5. Eliminate all variables which have the value greater than 0.9 values.
6. Go to the next highest ranked variables and go to step 4.

4.4. CLASSIFIER DESIGN USING BINARY CLASS SUPPORT VECTOR MACHINE

The classifier gives the boundary between separating classes. The accuracy of the classifier depends on the data provided for training purpose. The training algorithms available are least squares, back propagation, linear programming, etc., to design the classifier (Mohammad&Yaoyu, 2003). These existing algorithms consume less time, but have certain limitations such as poor classification accuracy and high misclassification rate, specifically when the size of the problem increases. So, Support Vector Machine is used for efficient training procedure. The static security assessment problem is treated as binary class pattern classification problem in this work.

SVM classifier reduces the generalization error by optimizing the trade-off between the number of training errors. SVMs in most of the cases are found to provide better classification results than other widely used pattern recognition classifiers. SVMs carry out the task of the binary classification by mapping the input data to a multidimensional feature space, and then it will construct an optimal hyper plane classifier separating the two classes with maximum margin. For minimization of the error optimal hyper plane is built by an iterative training algorithm in the SVM. Consider a training set $T = \{x_i, y_i\}$, where x_i is a real-valued n-dimensional input vector and $y_i \epsilon \{0, 1\}$ is a label that determines the class of data instance, x_i. For the construction of optimal separating hyper plane, the SVM classifier solves the following optimization problem.

$$\min_{w,b,\xi} \frac{1}{2} w^T w + C \sum_{i=1}^{l} \xi_i$$

Subject to

$$y_i (w^T Ø(x_i) + b \geq 1 - \xi_i; \quad \xi_i \geq 0, \quad i = 1,2,\ldots,l$$

Where w is the weight vector of the hyper plane, C is the penalty parameter proportional to the amount of the constraint violation, ξ_i is the slack variable, $Ø$ (.) is a mapping function called 'kernel' function and b is the threshold. The kernel function maps the data into the feature space from the input space where they are linearly separable. The concept of kernel mapping let on the SVM models to perform separations even with very complex boundaries. In this paper, Radial Basis Function kernel is used in the design of Binary class Support Vector Machine model.

4.4.1 CHOICE OF KERNEL

The Radial Basis Function (RBF) is used as the Kernel mapping function because of its widely known accuracy, and it is capable of handling non-linear relations between the class labels and input features.

4.4.2. ADJUSTING THE KERNEL PARAMETERS

Two parameters associated with RBF functions are to be selected (1) penalty parameter C and (2) RBF kernel parameter γ. The main aim is to identify optimal (C,γ) for the classifier to accurately predict unknown data. The grid search technique is used for selection of parameters because it is the most common method used to determine SVM parameters. In v cross-validation, the whole training set is equally divided into v subsets, v-1 subsets are used for training purpose, and one remaining subset is used for testing of trained classifier. This procedure is repeated for the various set of subsets. The cross-validation accuracy is calculated by the percentage of data samples correctly classified. Here Grid search is used on C and γ using 5-cross-validation. All pairs of C and γ were tried, and the one pair is selected which will give highest cross-validation accuracy. The sequence was used $C= \{2^{-5}, 2^{-4}, 2^{-3} \ldots 2^{15}\}$ and $\gamma = \{2^{-15}, 2^{-14}, 2^{-13} \ldots 2^{5}\}$.

4.4.3. TRAINING AND TESTING OF SVM CLASSIFIER

Once kernel parameters are selected SVM classifier is trained with the normalized input-output training data samples. On the satisfactory performance of the SVM classifier in the training phase, it is validated with test data samples to check its overall performance.

5. PERFORMANCE EVALUATION OF CLASSIFIER

The performance evaluation of trained classifier is validated using following performance measures:

1. Classification Accuracy (CA)

$$\text{Classification Accuracy (\%)} = \frac{\text{(No. of samples classified correctly)}}{\text{(Total no. of samples in data set)}} \times 100$$

2. Secure Misclassification Rate (SMCR)

$$\text{Secure Misclassification Rate (\%)} = \frac{\text{(No. of 0's classified as 1)}}{\text{(Total no. of insecure states)}} \times 100$$

3. Insecure Misclassification Rate (ISMCR)

$$\text{Insecure Misclassification Rate (\%)} = \frac{\text{(No. of 1's classified as 0)}}{\text{(Total no. of secure states)}} \times 100$$

In the static security assessment, it is necessary to make sure that the misclassification rate is as small as possible. Especially, the chances of an insecure state being wrongly predicted as secure states need to be reduced. So, the Classifier for the static security assessment must be designed to have high classification accuracy and less misclassification rate.

6. RESULTS AND DISCUSSIONS

The proposed work aims to develop a static security assessment Binary-classifier using Support Vector Machine. The proposed binary class SVM classifier is implemented in IEEE 14 and 30 bus test systems (Zimmerman&Gan, 1997). Data are generated by varying loads in the bunch of buses between 50% to 150% of their base case values arbitrary. Single line contingency is considered for each operating scenario. A load flow solution is done using Newton-Raphson method. Data generation is done with the help of MATPOWER toolbox (Zimmerman&Gan, 1997). LIBSVM software developed by C. C. Chang and C. J. Lin is used for SVM binary-classifier design (Chang&Lin, 2001). For calculation of the composite security index, we have to choose both alarm and security limits for bus voltages and line flows. ± 5% and ± 7% of the desired bus voltage values are taken as alarm and security limits for bus voltages. Security limit for the transmission line is calculated as explained in section 3. Alarm limit is taken as the 80% of security limit. For PV buses the specified bus voltage is taken as desired bus voltage and for PQ buses "1 p.u." is taken as the desired bus voltage. Approximately, 90% of data used for training and 10% of data used for testing. Feature selection is done by Single Ranking and Correlation Coefficient method. Results of feature selection and data generation for static security assessment are given in Table 2, Table 3 and Table 4. Table 2 gives the dimensionality reduction achieved by the Single Ranking and Correlation Coefficient method. The complexity of the classifier is reduced due to fewer numbers of feature used, it leads to reduction of training and testing time in the implementation of SVM. Results of the parameter selected by the Grid Search using 5-cross-validation are given in Table 5. Performances of the SVM-based binary-classifier on the IEEE standard test systems are given in Table 6.

	IEEE 14 Bus System	IEEE 30 Bus System
No. of Variables	106	214
No. of Feature Selected By Single Ranking Method	10	24
Dimensionality Reduction	9.43%	11.21%

TABLE 2. Dimensionality reduction due to single ranking feature selection method

IEEE 14 Bus System	V_9, V_{11}, V_{14}, V_{12}, V_{10}, P_{5-6}, P_{G1}, Q_{5-6}, P_{2-3}, P_{6-13}
IEEE 30 Bus System	Q_{G1}, Q_{G5}, Q_{G2}, P_{G1}, V_7, V_{28}, Q_{G8}, Q_{2-5}, V_{20}, P_{4-12}, P_{12-14}, Q_{6-7}, V_{14}, V_{15}, P_{15-18}, Q_{6-28}, P_{12-15}, Q_{9-10}, Q_{24-25}, V_{24}, P_{9-11}, V_{23}, Q_{28-27}, P_{15-23}

TABLE 3. Features selected by single ranking and correlation method

	IEEE 14 Bus System	IEEE 30 Bus System
Total Operating Scenarios	500	975
Total Operating Scenarios	312	743
Total Insecure Cases	188	232
Training Set		
Operating Scenarios	440	819
Secure Cases	281	614
Insecure Cases	159	205
Testing Set		
Operating Scenarios	60	156
Secure Cases	31	129
Insecure Cases	29	27

TABLE 4. Data generation for static security assessment

System	Selected parameters value (Parameter Ranges C = (2^{-5}, 2^{15} in step of 2^{1}) and γ = (2^{-15}, 2^{5} in step of 2^{1}))	
IEEE 14 Bus System	C = 128.0	γ = 1.0
IEEE 30 Bus System	C = 16384.0	γ = 0.0625

TABLE 5. Result of parameter selection of radial basis function using grid search and 5-cross validation

	IEEE 14 Bus System	IEEE 30 Bus System
Train Set		
5-Cross Validation CA (%)	99.091%	98.53%
Samples CA (%)	99.55% (438/440)	99.88% (818/819)
SMC (%)	0.629% (1/159)	0% (0/205)
ISMC (%)	0.356% (1/281)	0.1628% (1/614)
Test Set		
Samples CA (%)	93.33% (56/60)	98.07% (153/156)
SMC (%)	10.34% (3/29)	7.41% (2/27)
ISMC (%)	3.23% (1/31)	0.775% (1/129)
Overall CA (%) (Training and Testing)	98.80% (494/500)	99.59% (971/975)

TABLE 6. Performance evaluation of SVM classifiers on train set and test set

The performance of the SVM-based binary-classifiers on the test system is found quite satisfactory regarding the high classification accuracy and less misclassification rate. Secure Misclassification is not dangerous to the system because it is giving the false alarm. However Insecure Misclassifications are dangerous because here the insecure state is classified as the secure state and it is also called as the false dismissal. In IEEE 14 bus system, total four misclassifications occur in testing, in which three secure states classified as the insecure state, one insecure state is classified as the secure state. So, only one misclassification is dangerous. In the results of the IEEE 30 bus system, two secure states are classified as the insecure states; one insecure state is classified as the secure states. Less misclassification rate for insecure cases represents the effectiveness of the classifier.

7. CONCLUSION & POLICY IMPROVEMENT

This paper has proposed a binary-classifier based on the Support Vector Machine for the static security assessment of the power system. Selection of the weighting factor is eliminated due to the use of CSI instead of other performance indices. Thermal limit of the transmission lines is selected based on the loadability of the transmission line. The loadability of the transmission line is calculated by classifying transmission line into the short, medium and long transmission line. The classification of the power system indicates the security states to the operator, as the trained Support Vector Machine based classifier predicts the security state of the power system in the fraction of second; it helps to initiate control action as early as possible. So, Cascade tripping of the power system is avoided. The proposed binary-classifier was tested on IEEE standard test systems. Simulation results have proven high classification accuracy and fewer misclassification rates of the binary-classifier, Especially Insecure misclassifications are very less. Due to less time in the prediction of the security state and less insecure misclassification rate making it suitable for online implementation. The prediction of the security state in the small possible time for the present operating scenario will help utility to give reliable power to the society. Future work is the implementation of the Binary Class SVM to the larger systems.

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HYDROGEN COMPRESSED NATURAL GAS AND LIQUEFIED COMPRESSED NATURAL GAS: FUELS FOR FUTURE

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ABSTRACT: Due to the increasing demand of fuels natural gas is used not only in its original form but also as a mixture of several gases. Hydrogen Compressed Natural Gas (HCNG) and Liquefied Compressed Natural Gas (LCNG) are examples of such fuels. The paper narrates about two technologies:

(1) one in which the compressed natural gas is blended with the various proportions of hydrogen,

(2) while in case of Liquefied compressed natural gas (LCNG), Liquefied Natural Gas (LNG) is compressed to about 200 bar pressure to produce LCNG.

The paper also talks about the components necessary for LCNG and HCNG stations. In addition, the advantages and challenges related to these fuels are also described.

KEYWORDS

Natural Gas, Hydrogen, HCNG, LCNG

1. INTRODUCTION

Natural gas is considered as the most widely used alternative fuel for substitution of hydrocarbons (Bechtold, 1997). Natural gas is not only used in the form of LPG, CNG and LNG but also as Liquefied Compressed Natural Gas (LCNG) and Hydrogen Compressed Natural Gas (HCNG) (Shrestha et al., 1999). LCNG and HCNG are the two new trends in natural gas sector which are seen as the futuristic fuels of the world. In case of LCNG the liquefied natural gas is compressed up to a significant pressure and converted into compressed natural gas. It leads to the fueling of both CNG and LNG type vehicles at the same station point. While in case of HCNG a proportionate amount of hydrogen is blended to the compressed natural gas. At this type of station hydrogen as well as HCNG vehicles can be refuelled. These two fuels seem to be the future fuels which are also eco-friendly in nature. In case of India these are the developing technology which needs to be adapted.

2. HCNG

Since 1983 the mixture of natural gas and hydrogen have been used for test engine dating (Nagalimet al., 1983). In 1983 Nigalim B., Duebel F. and Schmillen K. conducted an experiment on AVL (Austrian based automotive consulting firm) engine fueled with 100/0, 80/20, 50/50 and 0/100 varying ratio of hydrogen and CNG. In year 1989, HCI (Hydrogen Components Inc.) started blending the various proportions of hydrogen to natural gas for testing the engine efficiency at Colorado State University (Hythane Company, LLC, 2007). The lean burn characteristic and the lower tail pipe emission is anticipated to be improved by the blending of hydrogen and CNG (Tunestal et al., 2002). Two types of fuels are formed by blending the various proportions of hydrogen to natural gas: one is HANG and another one is HYTHANE which is formed when 20% of hydrogen is added to 80% of CNG by volume. Typically the proportion of hydrogen, by volume for blending the natural gas varies from 8-50% (Table 2). Studies indicate that HCNG mixtures with 20-30% hydrogen by volume are optimal for vehicle performance and emission reduction (Del Toro et al., 2005). Refueling stations of HCNG requires a source for hydrogen and natural gas, which are pressurized and blended on-site for vehicle fueling. The supply of gas is through the natural gas infrastructure while the hydrogen is provided through electrolysis of natural gas reformation. By using the on-site electricity from local grid the phenomena of electrolysis is performed. Hydrogen from reformation of natural gas is supplied to sites by truck or produced on-site using low commercial reformers.

Figure 1 represents the integrated model of CNG and HCNG station where hydrogen as well as HCNG vehicles are fueled at same station. There are six major components which are required at combined CNG and HCNG stations, which are as follows:

1. Electrolyser
2. Source of Natural Gas
3. Source of Hydrogen
4. CNG/ Hydrogen Blender
5. CNG storage tanks
6. CNG and HCNG dispensers

Table 1 gives the comparative analysis of Hydrogen, CNG, 5% HCNG blend shows the characteristic values of HCNG with different hydrogen proportions. These properties confirm that the properties of HCNG lie between Hydrogen and CNG.

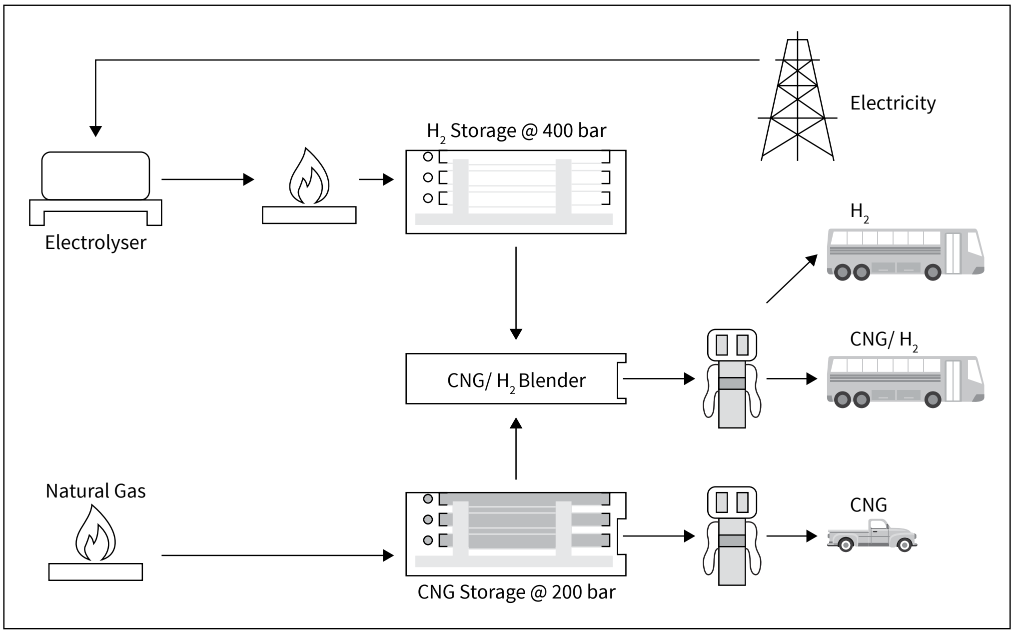

FIGURE 1. Integrated Model of CNG and HCNG Station *Source: modified after Pal, 2009*

Properties	Hydrogen	HCNG 5	Ch_4	Gasoline
Limits of flammability in air, [vol.%]	4-75	5-35	5-15	1.0-7.6
Stoichiometric composition in air, [vol.%]	29.53	22.8	9.48	1.76
Minimum energy for ignition in air, [mJ]	0.02	0.21	0.29	0.24
Auto ignition temperature, [K]	858	825	813	501-744
Flame temperature in air, [K]	2318	2210	2148	2470
Burning velocity in NTP (Normal Temp. & Press.) air, [cms^{-1}]	325	110	45	37-43
Quenching gap in NTP air, [cm]	0.064	0.152	0.203	0.2
Normalized flame emissivity	1.0	1.5	1.7	1.7
Equivalent ration flammability limit in NTP air	0.1-7.1	0.5-5.4	0.7-4	0.7-3.8
Methane Number	0	76	80	-

TABLE 1. Composition of Properties of Hydrogen, CNG and HCNG 5 with Gasoline

Properties	CNG	HCNG 10	HCNG 20	HCNG 30
H2 [% vol.]	0	10	20	30
H2 [% mass]	0	1.21	2.69	4.52
H2 [% energy]	0	3.09	6.68	10.94
LHV [$MJkg^{-1}$]	46.28	47.17	48.26	49.61
LHV [$MJNm^{-3}$]	37.16	34.50	31.85	29.20
LHV stoich. Mixture [$MJNm^{-3}$]	3.376	3.368	3.359	3.349
LHV - Lower Heating Value				

TABLE 2. Properties of CNG and HCNG Blends with different hydrogen content

Source: Xu et al., 2010

2.1 ADVANTAGES OF HCNG:

• It requires only a small hydrogen storage and a column for the mixing of hydrogen with natural gas at existing CNG stations.

• Safety components are similar to the CNG. HCNG is easy and safe to use than hydrogen as it contains very low energy content from hydrogen i.e., up to 30% by volume.

• HCNG reduces the engines unburned hydrocarbon emissions and speed up the process of combustion.

• The engines fuel efficiency is improved by blending the CNG from hydrogen which lowers the fuel consumption of vehicle.

• The thermal efficiency and fuel economy is also increased by HCNG.

2.2 DISADVANTAGES

• HCNG storage and supply infrastructure is a big challenge.

• System performance and material compatibility needs to be taken in account.

• Emission testing of HCNG blends needs to be done with various ranges of hydrogen.

3. LCNG

LCNG stations are the type of stations which make LNG gasified to become CNG and fuel both LNG and CNG vehicles. The source of natural gas at LCNG stations are through LNG storage tanks, where the dispenser for both LNG and CNG vehicles are available. Cryogenic pumps are used at LCNG stations for moving the LNG from an insulated storage vessel through dispenser into the vehicle. To produce CNG from LNG the gas is compressed up to 300 bar pressure in a controlled manner so that it can be dispensed at the right pressure as CNG. The LCNG stations use LCNG skid to pump the LNG liquid through high-pressure piston pump into the vaporizer, to make it become gas and save it into the cylinder or well, then it uses CNG and LNG dispensers to refuel the vehicles. An LCNG station has cryogenic LNG pumps and LNG storage tanks. The LCNG stations generally have high capital but low operating costs in comparison to CNG and LNG stations. LCNG stations mainly consist of:

- Storage vessel – tanker truck delivers LNG to storage vessel
- Cryogenic pump – moves LNG from storage to dispenser and vaporizer
- Vaporizer – converts LNG to gas and controls pressure to dispense it as CNG
- Dispenser – both LNG and CNG dispensers

Figure 2 represents the combined LNG and CNG stations which can fuel both LNG and CNG vehicles at the same station points. There are generally two basic types of LCNG stations one uses the cryogenic centrifugal pump whereas the other uses the boil off recovery system to convert LNG to CNG.

3.1 ADVANTAGES

- It has low capital cost than LNG and CNG stations.
- High refueling capacity for LNG vehicles.
- It can serve to both LNG as well as CNG vehicles both.
- It has flexibility to refuel heavy and light commercial vehicles.
- Low space requirement.

3.2 DISADVANTAGES

- High operational cost.
- Not capable to fuel the high pressure trucks.

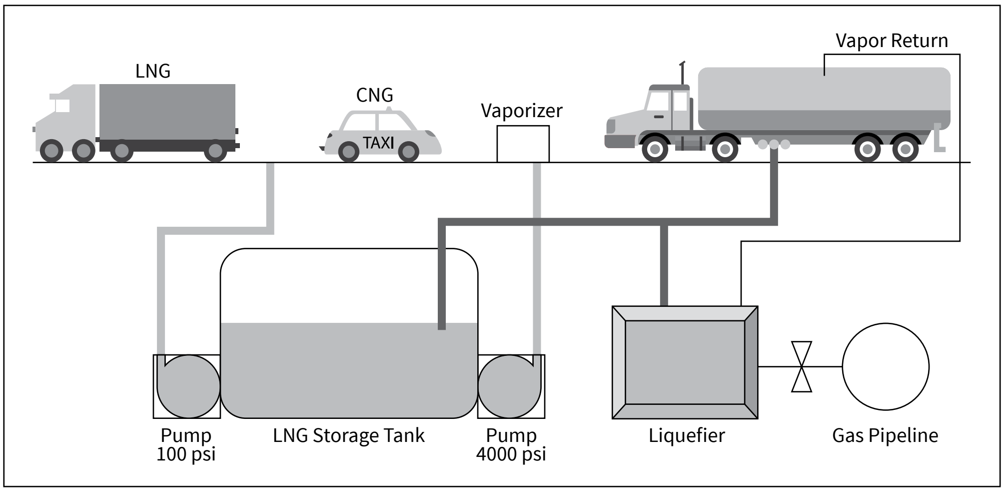

FIGURE 2. Liquefied Compressed Natural Gas (LCNG) Station *Source: Wegrzyn and Litzke, 1999*

4. CONCLUSION

The paper gives an overview about the two futuristic fuels LCNG and HCNG. It talks about the types of fuels formed due to the blending of hydrogen at different proportions. The paper articulates the six major components present at HCNG stations along with the comparative analysis of various properties of Hydrogen, HCNG5, CNG and Gasoline. The paper also emphasises on the advantages and disadvantages of HCNG and LCNG. Along with HCNG it talks about the four major components of LCNG which are storage vessels, cryogenic pump, vaporizer and dispenser. It also depicts the integrated model for LCNG and HCNG stations. It is found from various literature that the storage and supply infrastructure is a big challenge in terms of HCNG vehicles. The LCNG techniques is still in a need to be adapted in India while HCNG pilot projects are going on in two states of India. The initiative is taken by Indian oil, the first HCNG dispensing system was set up at Faridabad in 2005 where the HCNG @ 250bar pressure is served. While another station is established in Dwarka, Delhi in 2009 where HCNG @ 250bar pressure is served. The technology of LCNG is significantly adapted in Europe, Brazil, etc.

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SIMULATION ON MPPT BASED SOLAR PV STANDALONE SYSTEM

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ABSTRACT: The present work demonstrates the simulation for PV module with the maximum power point tracking (MPPT) control system in standalone mode. The operation of the proposed system is tested with DC loads. The perturb and observed (P&O) algorithm is demonstrated in this system. The DC load is connected with the system and performance has checked under various atmospheric conditions to verify the efficiency and effectiveness of the algorithm under various atmospheric conditions. The system used in simulation comprises of the single module of solar PV (240W). The concept is demonstrated using simulations done in PSIM ® 9.3.4 software.

KEYWORDS

Maximum power point tracking (MPPT), Photovoltaic (PV), Standalone system

1. INTRODUCTION

The global rise in annual energy demand, global warming, and unstable fossil fuel economy are driving the world to shift towards renewable energy sources for a sustainable future. Wind and solar power are the two renewable energy resources that have increasing share in electricity generation due to the ease of availability, mature technology, and comparatively lower costs. The report published by the Government of India (GoI) on 31st May, 2015 states that about 19,706 Indian villages are in need of electrification (Progress Report of Village Electrification, 2016). The main challenges in achieving the target of electrification of a rural country are remote locations far from grid connection, unsuitable terrains, and cost of transmission. Hence, the possible solution lies hidden in renewable energy systems. Most of the parts of India annually experience bright and sunny days for almost 250 to 300 days (Information of Solar RPO, 2016). Moreover, as per the report by Ministry of New and Renewable Energy, GoI, states like Andhra Pradesh, Gujarat, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Orissa, and Tamilnadu have high potential to harness the wind energy. Thus, wind energy system (WES) and photovoltaic energy system (PVES) are seen as essential resources to meet the challenge of rural electrification.

If rural electrification is achieved with photovoltaic (PVs), then to keep the area powered up at night time large battery backup would be required. This would increase the cost of energy and may in some cases lead to the solution being economically infeasible. Another possible option therefore, is hybridization with other renewable energy sources.

In recent times, low voltage distribution systems supported by renewable energy systems and other energy storage elements in conjunction with the grid, termed as hybrid energy systems, are preferred to reduce carbon emissions and reliance on fossil fuels (Liu, Wang, & Loh, 2011). The academic and industrial interest in hybrid energy systems is evident from the number

of related literature in recent times (Mendis, Muttaqi, Sayeef, & Perera, 2012; Valenciaga, & Puleston, 2005, Nehrir, LaMeres, Venkataramanan, Gerez, & Alvarado, 2000, Ahmed, Miyatake, & Al-Othman, 2008, Hirose, & Matsuo, 2012; Kumaravel & Ashok, 2015, Eroglu, Dursun, Sevencan, Song, Yazici, & Kilic, 2011). A review of different stand-alone hybrid solar systems for off-grid and rural electrification with load type, design capacity and its outcome is presented in (Mahesh, & Sandhu, 2015).
Off grid systems are reported and reviewed in (Akikur, Saidur, Ping, & Ullah, 2013) Different hybrid standalone systems, such as stand-alone solar PV system, hybrid solar PV wind system, hybrid solar PV diesel system and hybrid solar PV wind diesel systems are also discussed in the review (Akikur et al., 2013). Similarly, Mahesh et al. have presented critical reviews of available hybrid wind-PV with battery backup (Mahesh et al., 2015). Due to wide acceptance of AC supply, the hybrid energy systems were analyzed for AC supply. PVES and BESS provide DC supply, whereas WES or diesel engine systems required AC-DC and then DC-AC conversion. Hence, the AC systems suffer from the increased stage of power conversion, increased power electronics converters and associated losses. DC system can be seen as an alternative where the power conversion stages are reduced. In remote rural locations, the DC supply can feed the LED lighting loads and fan loads. Moreover, many of the consumer electronics convert AC-DC and, in some cases, DC-AC. In addition to this, DC systems have the merits of (i) higher efficiency because of absence of inverter between the DC link and load, (ii) absence of grid synchronization, reactive power management and related issues, and (iii) DC system has inherent fault ride through capability in case of grid connected systems (Kakigano, Miura, & Ise, 2010). Hence, isolated DC energy system with PV installation is an ideal for remote rural electrification. Low voltage hybrid DC system for a residential complex is reported by Hiroaki et al. al.,(2010). DC energy systems with local DC grid involve DC-DC converters to interface the solar or battery system with the point of common coupling. The DC-DC converters regulate the voltage at the point of common coupling and at the same time ensure that the photovoltaic panels are loaded in such a way that the maximum power is drawn. Maximum power point tracking algorithm estimates the current or voltage which when drawn or maintained across from the PV panel ensures that maximum power is delivered. Variations in these conditions can affect not only the DC current and voltage levels of the energy resources but also the system stability. Traditionally, proportional integral (PI) controllers are employed to regulate the DC supply voltage and ensure that the PV is operating at maximum power point.

The power circuit of PV module consists of series connected PV cells, DC-DC converter, and load. The voltage and current sensors are employed to measure the PV voltage (V_{PV}) and PV current (I_{PV}). The PV modules are identified with their wattage capacity as well as other parameters like open circuit voltage (V_{OC}), short circuit current (I_{SC}), rated voltage or maximum power voltage (V_R), rated current (I_R) or MPP. Fig. 1 shows the equivalent circuit of single diode PV which is used in the analysis. This model consists of photo current source, diode, series resistor and parallel resistor. S indicates light intensity (Kollimalla et al., 2013) The series connection of the PV cells will become module and series, or parallel connections of many modules will become an array. The radiation and temperature are measured concerning standard test conditions (STC) with 1000W/m^2 radiation and 25^{0}C temperature of the module as a reference.

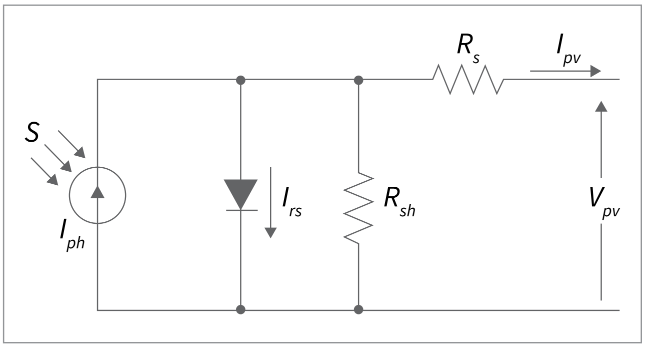

FIGURE 1. Equivalent Circuit of PV Cell

The series connection of these cells will become module and series or parallel connections of a number of modules will become an array. The non-liner IV characteristics of PV cell is given by,

$$I_{PV} = I_{ph} - I_{rs}\,(e^{\frac{q(V_{pv}+I_{pv}R_s)}{AkT}} - 1) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \qquad (1)$$

Where,
I_{pv} is Output current (A)
I_{ph} is Light generated current or photo current (A)
I_{rs} is Diode reverse saturation current
V_{pv} is Output voltage (V)
q is Electron charge (= 1.609x10^{-19} C)
A is Diode ideality constant
k is Boltzmann's constant (= 1.38x10^{-23} J/K)
T is cell absolute temperature (^{0}K)

Moreover, other parameters of PV module are obtained from Solarex MSX-60 data sheet. Using tutorial file of PSIM the two strings have made by connecting multiple modules in series and parallel as a single panel per string as shown in the block diagram.

2. BRIEF OF SOLAR MPPT ALGORITHMS AND ITS IMPLEMENTATION IN PSIM ® 9.3.4 SOFTWARE

The MPPT algorithms are implemented to the PV modules with boost converters to track the operating point under different varying isolation conditions which could deviate from standard test conditions. These algorithms are used to track the power under different varying radiations. There are various MPPT techniques available in literature. A large number of studies have been done on Incremental conductance method and Perturb and observe method.

P&O method finds the maximum power point of PV modules by means of iteratively perturbing, observing, and comparing the power generated by the PV modules. It is widely applied to the maximum power point tracker of the photovoltaic system for its features of simplicity and convenience.

In majority of the cases perturb and observe (P&O) algorithm and incremental conductance (INC) are used. The P&O algorithm is found to be easy in implementation and used for battery charging applications. In this method, the operating voltage or current of the PV module is perturbed and then the power obtained is observed to decide the direction of further changes in the voltage with change in atmospheric conditions.

If perturbation increases the power, then the voltage or current is kept on changing in the same direction until the power begins to fall. The algorithm measures the instant voltage (V_t) and current (I_t) to calculate the power (P_t) and then compare it with last calculated power (Pt-1). The algorithm continuously perturbs the system if the operating point variation is positive; otherwise, the direction has changed.

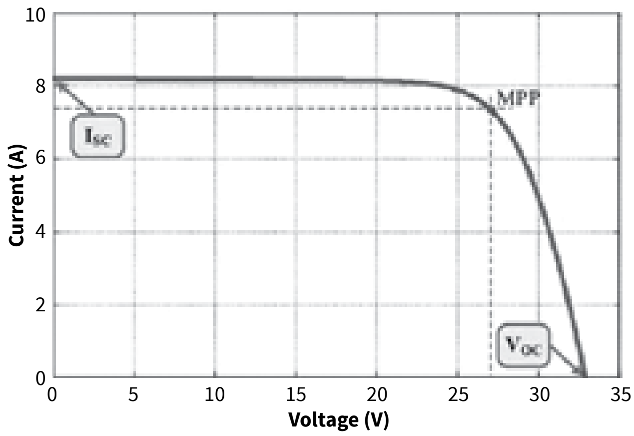

FIGURE 2. PV Current v/s Voltage Characteristic. [18]

3. SYSTEM CONFIGURATION AND BLOCK DIAGRAM

The block diagram of the standalone system is shown in fig. 3. The system comprises of single PV module connected with DC-DC converter. The reference signal is generated from MPPT algorithm and compared with actual current drawn from the PV. The algorithm has been programmed in DLL (Dynamic link library) block, available in PSIM ® 9.3.4 software. Simple PI controller with closed loop has been demonstrated in the same software. The PI controller is tuned for various operating conditions. The change in operating conditions results change in duty cycle of the switch. The efficiency of algorithm is found from superimposing two curves of available power and tracked power from the PV. To check the effectiveness of the algorithm square wave with in specific range of radiation is applied as an input to the PV with 25^0 C of PV temperature. In this simulation the switching frequency is taken as 10 kHz and used for generation of gating pulse. These results are demonstrated in next section.

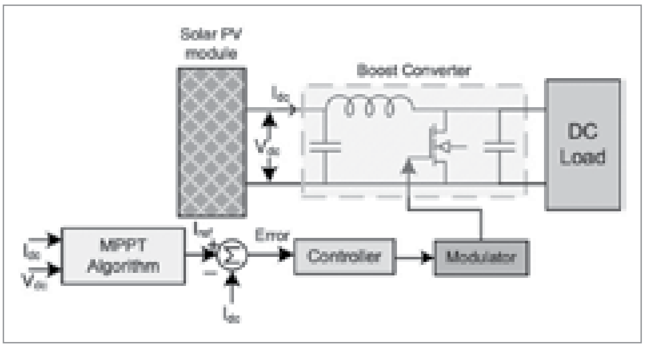

FIGURE 3. Block diagram of PV standalone system

4. SIMULATION OF STANDALONE SYSTEM AND RESULTS

Fig. 4 gives the simulation of solar module used as a power generation with its MPPT; here the single panel of 240W is simulated in PSIM ® 9.3.4 software and results are compared with and without perturbation applied to radiation. The MPPT code has developed in DLL block available in PSIM with visual studio C++. The perturbation is applied to the input of the PV panel using square wave input within the specific range of radiation. The closed loop DC-DC converter is used in boost mode to maintain constant voltage within the specific range of load. The calculation of inductor and capacitor for this specific work has done using equations available in Michael Green (2012). Further, the generated power from PV (P_{max} in simulation) is compared with actual power (Power) which can be further used for the measurement of the efficiency of the algorithm. In fig. 4 complete simulation circuit is shown. The current perturbation algorithm is used in this work proposed in Kollimalla & Mishra (2014). The MPPT algorithm generated the reference current and compared with the actual current depending upon the short circuit current. This current is compared with actual PV current generated by the module. PI controller is fine tune with specific limits and the gate pulse is generated.

Fig. 5 and fig. 6 shows the response of the system when the perturbation is applied to the radiation. After applying perturbation on solar PV module, MPPT efficiency is measured by superimposing two curves of maximum available power (named P_{max} in fig. 5) and tracked power (named Power in fig. 5). This can be done at different radiations. Similarly, results may be obtained with changing in loads as well as module temperature. Fig. 7 shows actual power consumed at various radiation levels.

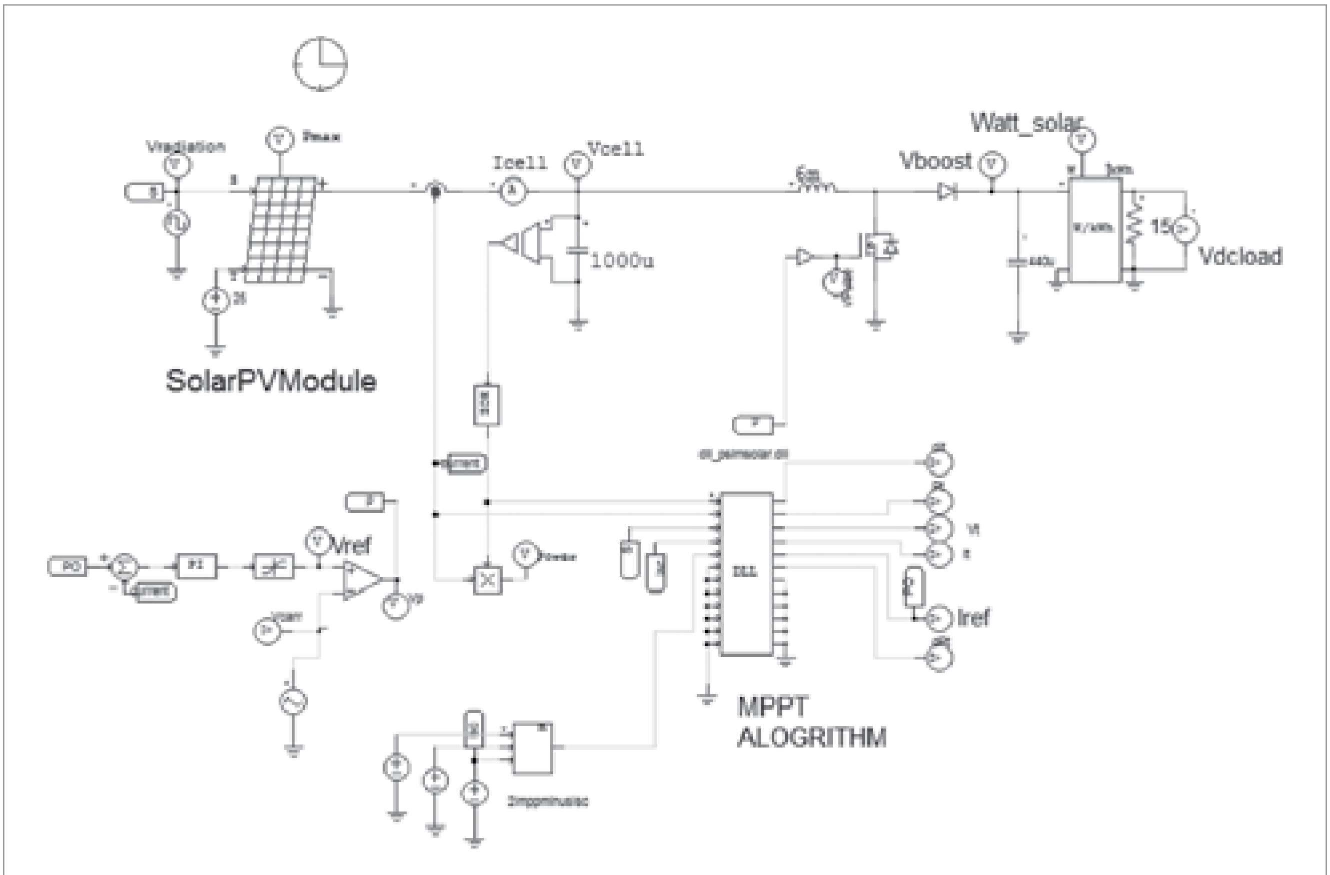

FIGURE 4. PSIM based simulation circuit with P&O MPPT Algorithm - Single PV Module

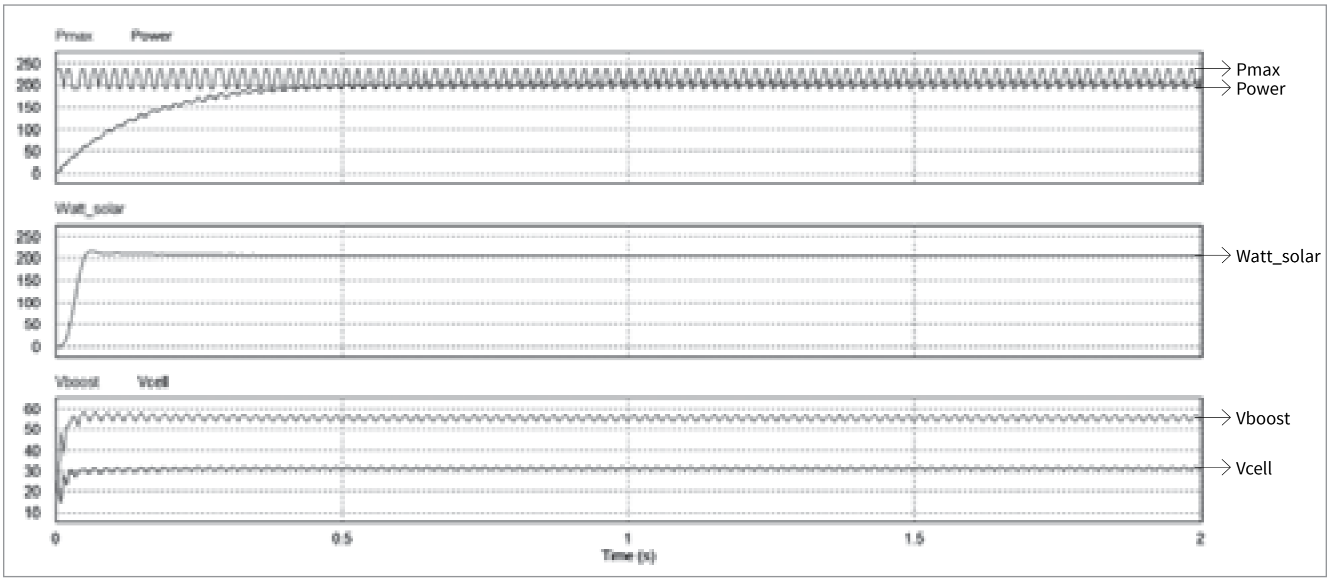

FIGURE 5. Result of Maximum Power from PV (P_{max}), Power Consumed by Load (Watt_Solar), Tracked Power (Power) and Response of Boost Converter at Constant Radiation. (MPPT Efficiency 86.91%)

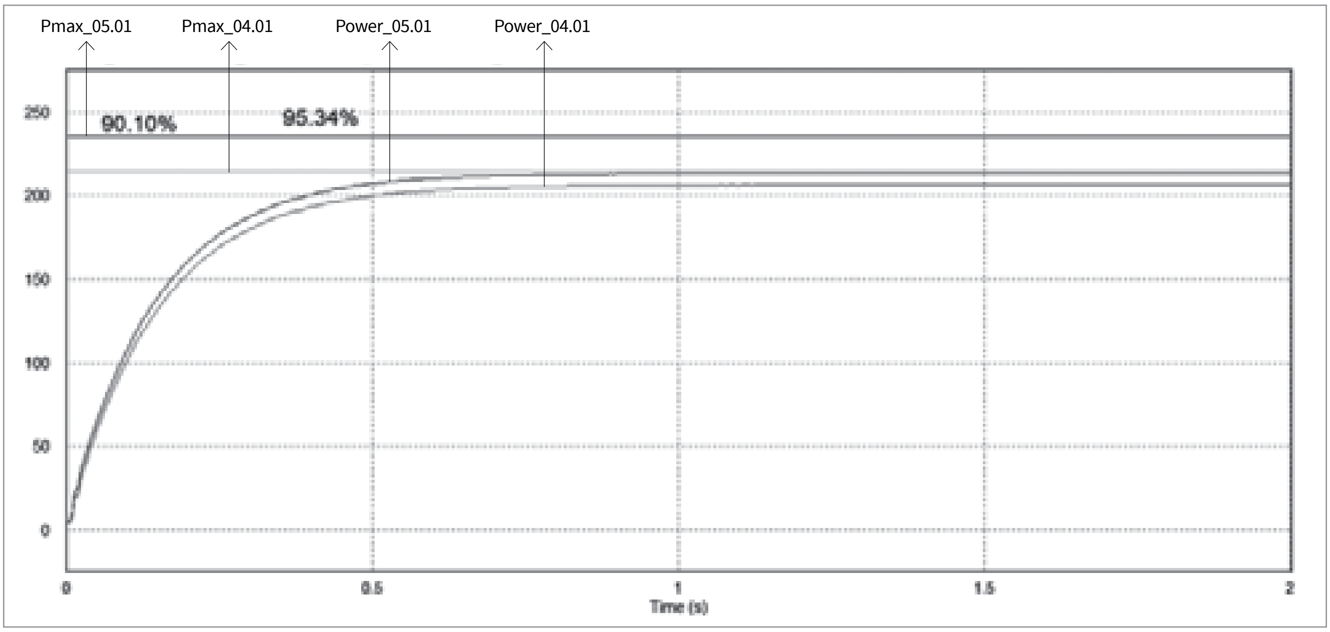

FIGURE 6. Maximum power and tracked power at different radiation with its efficiency

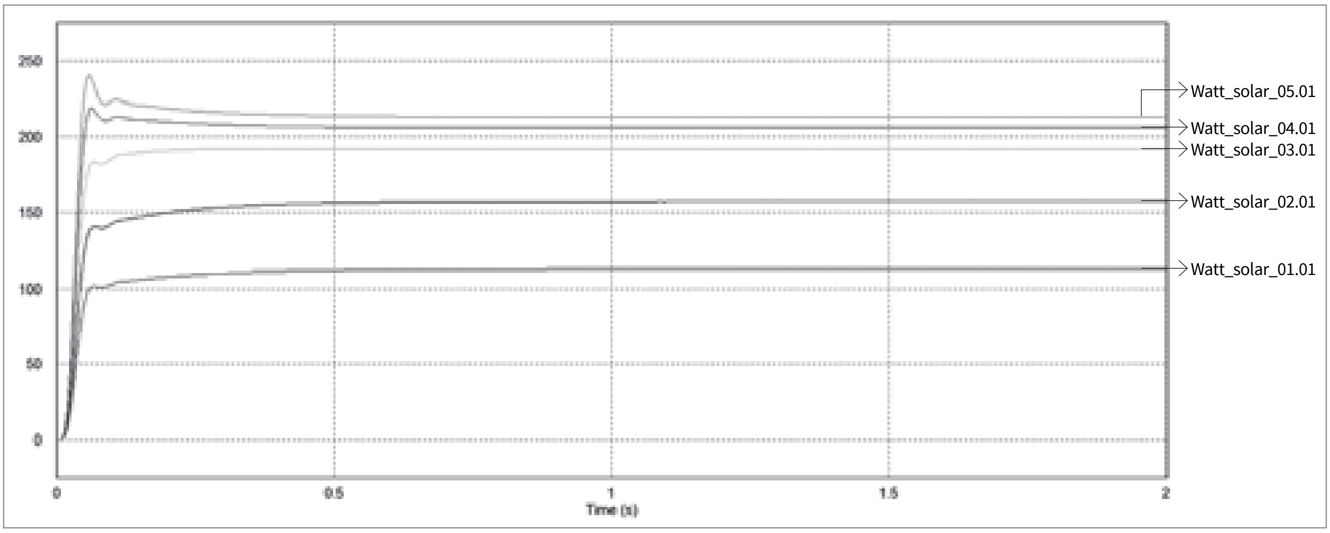

FIGURE 7. Actual power consumed at different radiations by wattmeter

Then the same results are demonstrated and verified for 30 such 60W each module connected in series and comparison was done with MPPT algorithm and without MPPT algorithm. Fig. 8(a) and (b) are showing the comparison of actual power and tracked power with and without MPPT algorithm. The MPPT efficiency is observed at 90%.

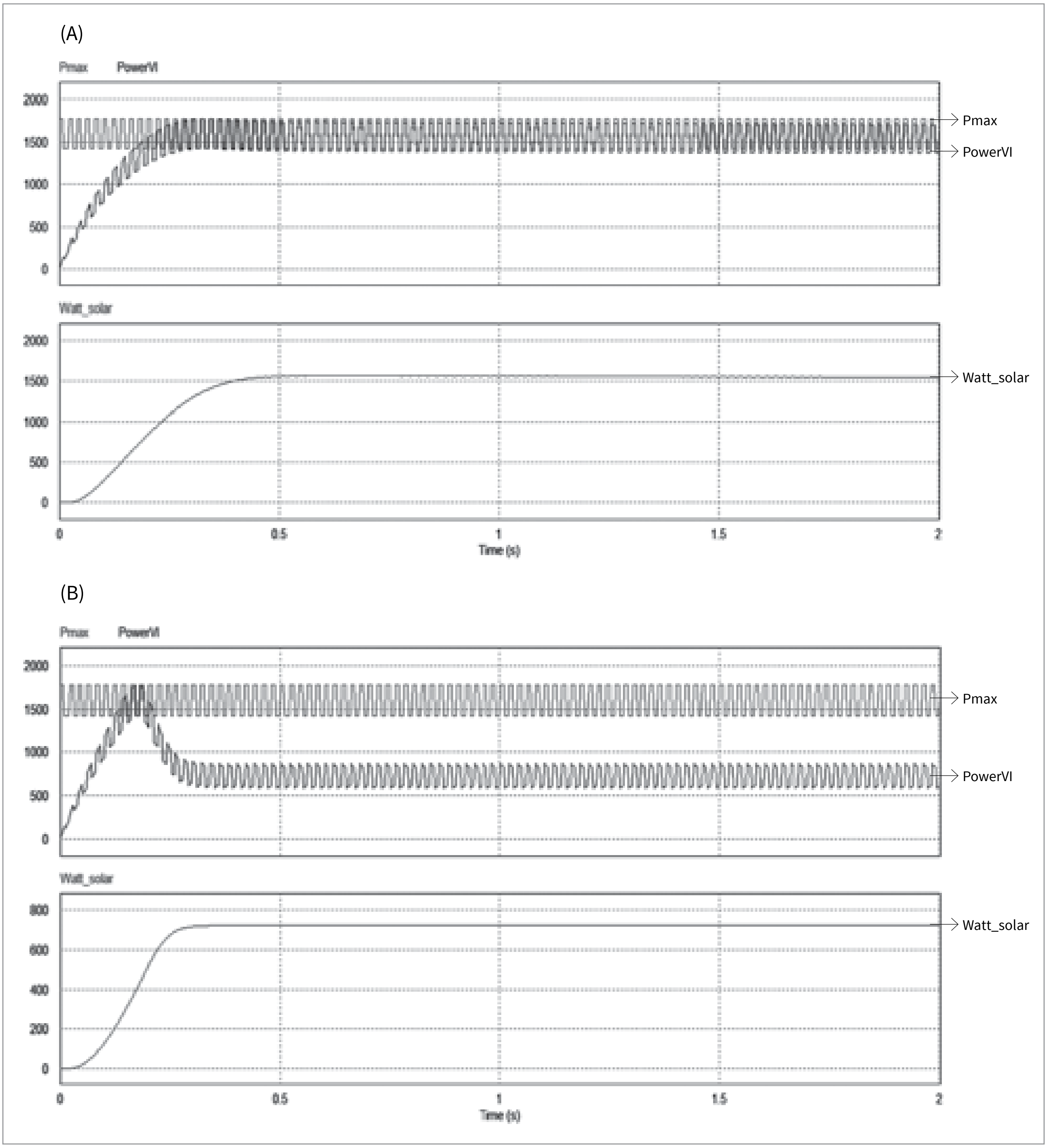

FIGURE 8. Comparison of Maximum Power (P_{max}), Tracked Power (PowerVI) and Consumed Power by Load (Watt_Solar) (A) with and (B) Without MPPT Algorithm.

5. CONCLUSION

The simulation for solar PV with MPPT has demonstrated, that maximum power is tracked with different atmospheric conditions and observing MPPT efficiency at various radiation levels taking current as perturbing variable. For variable perturbation in radiation around STC, the MPPT efficiency is found near about 90% on an average. Moreover if still the load demand is increased one can install more number of modules in series as well as parallel depending upon demand.

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5

LONG TERM SUSTAINABILITY OF NUCLEAR POWER IN INDIA - PROSPECTS AND CHALLENGES

Vipin Shukla, Vivek J. Pandya and C. Ganguly

ABSTRACT: Nuclear power is emerging as a viable carbon – free option for India to meet the ever-increasing demand of base – load electricity at an affordable price, in a safe, secured and sustainable manner. Since the 1970s, India had been pursuing a self-reliant indigenous nuclear power program linking the fuel cycles of Pressurized Heavy Water Reactor (PHWR), Fast Breeder Reactor (FBRs) and thorium-based self-sustaining breeder in stage 1, 2 and 3 respectively, for efficient utilization of modest low grade (0.03-0.06 % U_3O_8) uranium reserves but vast thorium resources. Natural uranium fueled PHWR is the backbone of the program. India has achieved industrial maturity in PHWR and the related uranium fuel cycle technology. Presently, 21 reactors are in operation, including 16 units of PHWR 220 MWe, 2 units of PHWR 540 MWe, 2 units of Boiling Water Reactor (BWR) 160 MWe and a (Water Water Energy Reactor) VVER 1000 MWe. Six reactors including a VVER 1000, 4 units of PHWR700 and a Prototype Fast Breeder Reactor of 500 MWe (PFBR 500) is in an advanced stage of commissioning, as the first step to commercialization of Fast Breeder Reactor (FBR) technology and related 'closed' fuel cycle. Two additional FBRs of 600 MWe each and an integrated fast reactor fuel cycle complex are planned at the PFBR 500 sites. Since the year 2009, India has been given access to international uranium market and reactor technology. This has helped the country to enhance the expansion of nuclear power program in collaboration with overseas vendors. Negotiations are underway to set up several Generation III + light water reactor (LWR) parks with the assistance of leading reactor vendors like Rosatom, Russia (for VVER1000), Areva, France (for EPR 1650), Westinghouse, USA (for AP 1000) and General Electric, USA (for ESBWR 1350). These reactor vendors have given assurance of life time supply of low enriched uranium oxide fuel for these reactors. Several reactor sites are being developed for at least 12 additional indigenous PHWR 700 reactors. The target is to have ~ 45,000 MWe nuclear power by 2030. Since the last six years, India has also been importing natural uranium oreconcentrate (UOC) and finished natural UO_2 pellets tofuel the ten PHWR 220 units at Rawathbhata, Kakrapara and Narora. India has also been importing enriched UO_2 fuel for the two BWRs at Tarapur and the two VVERs at Kudankulunm. The present paper summarizes the on-going and the expanding nuclear power program in India highlighting the challenges of availability of uranium and plutonium for manufacturing nuclear fuels.

KEYWORDS

PHWR, BWR, VVER, FBR, LWR

1. INTRODUCTION

India is the third largest generator of electricity in the world and has presently an installed Electric power exceeding 300 GWe. Ironically, nearly 300 million people in India, out of the total population of 1.25 billion, do not have any access to electricity. The annual per capita consumption of electricity in India is in the range of 1000 kWh which is less than half of the global average. Hence, the installed electric power has to be augmented to ~ 1200 GWe by 2050 in order to bridge the gap between electricity demand and supply. Fossil fuel, in particular coal, contributes to some 70% of the electricity today and is likely to dominate the electric power market in India at least till 2030. However, India has pledged in the UN climate change meeting at Paris in December 2015 to reduce CO_2 emission relative to its GDP by 33-35% from 2005 level by 2030 and also declared that 40% of the country's electricity will come from non-fossil fuel-based resources, including solar, wind and nuclear, by 2030. Nuclear power is, therefore, emerging as an inevitable option for India to meet the ever increasing demand of high base-load electricity at an affordable price in a safe, secured and sustainable manner, leaving minimum carbon footprint.

The Department of Atomic Energy (DAE), Government of India is responsible for nuclear power and related activities in India. The Nuclear Power Corporation of India Limited (NPCIL), a public-sector undertaking (PSU) of DAE, is responsible for design, construction, operation and maintenance of all water cooled, thermal neutron reactors in India. NPCIL has generated some 37,835 million units of electricity, the highest ever nuclear electricity in India. But the contribution of nuclear electricity has so far been a meager 3% of the country's electricity production. Presently, NPCIL's reactor fleet consists of 21 reactors of which two are Boiling Light Water cooled and moderated Reactors (BWRs) of 160 MWe each, sixteen are Pressurized Heavy Water cooled and moderated Reactors (PHWRs) of 220 MWe each and two units of PHWR 540 MWe and a VVER 1000 MWe, the Russian acronym of Pressurized light water cooled and moderated Reactor (PWR). The VVER 1000 unit at Kudankulum Nuclear Power Plant (KKNP1) started commercial operation on December 31, 2014. Six reactors with total capacity of 4300 MWe are under construction. These include 4 units of PHWR 700 MWe, the second VVER 1000 unit at Kudankulum (KKNP2) and a Prototype Fast Breeder Reactor of 500 MWe (PFBR 500). The design, construction, operation and maintenance of Fast Breeder Reactors (FBRs) in India, including PFBR, is the responsibility of Bharatiya Navikiya Vidyut Nigam (BHAVINI), another PSU of DAE.

Since the last few year, India has been negotiating with leading Light Water Reactor (LWR) vendors like Rosatom - Russia, AREVA - France, Westinghouse - USA and General Electric - USA for joint construction of Generation III+ LWR parks along the coast lines of India. The sites for the LWR parks have been allocated. The reactor vendors have guaranteed life time supply of zirconium alloy clad, low enriched uranium (< 5 % U235) oxide fuel assemblies and have agreed to give the rights of reprocessing spent nuclear fuels to India. Simultaneously, NPCIL has planned at least 12 additional units of indigenous PHWR 700 at different inland sites. Hereafter, no more PHWR 220 units will be constructed and the focus will be on large (700 MWe and higher) PHWR and LWR parks. The World Nuclear Association (WNA), London has been updating the status of nuclear power program in India (Nuclear Power in India, 2017).

The present paper summarizes the on-going and upcoming nuclear power program in India, highlighting the challenges associated with the rapidly expanding nuclear power program, availability of uranium and plutonium for manufacturing nuclear fuels and the related issues.

Table 1 summarizes the location, capacity and safeguards status of the 21 operating power reactors and the 6 reactors that are under construction.

The revised short term targets of nuclear power in the country are ~ 14,600 MWe by 2021 and ~ 27,500 MWe by 2032. The long-term target is to have at least 25% of the electricity from nuclear power station by 2050.

Figure 1. shows the location of the sites in India where the 21 nuclear power reactors are in operation and 6 are under construction (Uranium 2014: Resource, Demand and Production, 2015). Figure 2. shows the sites in India where indigenous PHWR 700 units andFBRs and imported Generation III + LWRs have been planned in coming years.

Power Station & Number of Reactors	Location & State	Type & Capacity (MWe)	Fuel	Uranium Source	Safeguard Status
Tarapur Atomic Power Station (TAPS 1 & 2)	Tarapur, Maharashtra	BWR 160	Enriched UO2; U^{235}: 1.6%, 2.1% & 2.66 %	Imported UO2 pellets Russia	Under IAEA Safeguards
TAPS 3 & 4	Tarapur, Maharashtra	PHWR 540	Nat UO2	Indigenous	Not under Safeguards
Rajasthan Atomic Power Station (RAPS 1,2,3,4,5 & 6) **RAPS 7 & 8**	Rawathbhata, Rajasthan **Under Construction**	PHWR 220 **PHWR 700**	Nat UO2	Imported	Under IAEA Safeguards
Madras Atomic Power Station (MAPS 1 & 2)	Kalpakkam, Tamil Nadu	PHWR 220	Nat UO2	Indian Mines & Mills	Not under Safeguards
Narora Atomic Power Station (NAPS 1 & 2)	Narora, Uttar Pradesh	PHWR 220	Nat UO2	Imported	Under IAEA Safeguards
Kakrapar Atomic Power Station (KAPS 1 & 2) **KAPS 7 & 8**	Kakrapar, Gujarat **Under Construction**	PHWR 220 **PHWR 700**	Nat UO2	Imported	Under IAEA Safeguards
Kaiga Atomic Power Station (KGS 1, 2, 3 & 4)	Kaiga, Karnataka	PHWR 220	Nat UO2	Indian Mines & Mills	Under IAEA Safeguards
Kudankulum Nuclear Power Plant (KKNPP1)**KKNPP 2**	Kudankulum, Tamil Nadu **Under Construction**	VVER 1000 **VVER 1000**	Enriched UO2	Imported Fuel Assemblies	Under IAEA Safeguards
Prototype Fast Breeder Reactor	Kalpakkam, Tamil Nadu	**PFBR 500**	(U, Pu) O2	Indian Fuel	Not under Safeguards

TABLE 1. Location, capacity, fuel and safeguards status of nuclear power reactors in India.

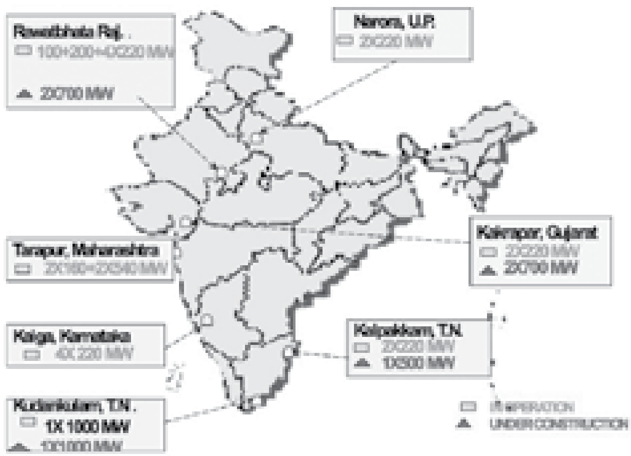


FIGURE 1. The locations of the 21 nuclear power reactors that are under operation and that are under construction in India

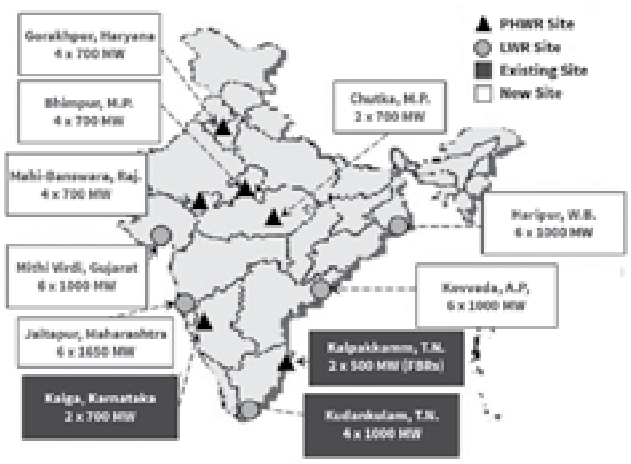


FIGURE 2. Location of the sites in India where indigenous PHWR 700 & FBRs and the imported generation III + LWRs have been planned.

2. NUCLEAR POWER REACTOR TECHNOLOGY AND THEIR APPLICATIONS IN INDIA

The present generation of nuclear power reactors, all over the world, derives energy from the fission of U235, the only fissile material in nature. Natural Uranium (NU) contains 99.3% U238, a fertile isotope and only 0.7% U235. NU is not only the basic raw material for U235 – based fuel but also produces the fissile isotope Pu239 in a reactor by neutron capture of the fertile U238 isotope followed by β-decay. Nearly 30% of the fission heat energy in a reactor is produced by in-situ fission of Pu239. Presently, 99% of the 439 operating nuclear power reactors in the world, with total installed power of ~ 480 GWe, are thermal neutron reactors. LWRs, consisting of PWR, VVER and BWRs account for nearly 85% of the reactors. The PHWRs, also known as CANDU in Canada and other countries, contribute to some 12% of the reactors. The PHWRs and LWRs use natural uranium and low enriched uranium (LEU:< 20 % U235) containing up to 5% U235 respectively as fuel in the form of high density cylindrical UO2 pellets that are stacked and encapsulated in zirconium alloy cladding tubes. The fuel rods thus produced are assembled in circular (in PHWRs), square (in PWRs & BWRs) or hexagonal (in VVERs) configurations to form fuel assemblies.

The spent LWRs and PHWRs fuels contain the fissile isotope Pu239 and other isotopes of plutonium, namely, Pu240, Pu241, Pu242 & Pu238, minor actinides (Np, Am & Cm) and fission products. The plutonium could be recycled in LWRs and PHWRs in combination with U238 but in spite of multiple recycling of the actinides, in thermal neutron reactors, the effective utilization of natural uranium resource is < 1%. Most of the uranium is locked as U238 in tailings of U235 enrichment plants and in spent fuels. The plutonium is best utilized in fast breeder reactors (FBRs), in combination with U238, to breed more Pu239 than what is consumed as fuel. FBRs are more expensive than water cooled reactors but are required for long term sustainability of nuclear power. With FBRs and 'closed' fuel cycle involving multiple recycling of actinides at least 60% of natural uranium resources could be utilized. Now, there are only 2 commercial FBRs that are in operation. Both are in Russia. LWRs, in general, and PWRs (including VVERs) will continue to dominate the world nuclear power market till the FBRs are commercially introduced.

The identified conventional uranium resources worldwide, recoverable at a price < 260 US$/kg U, is in the range of 7.6 million tons and the annual demand of uranium from mine to fuel the operating reactors is in the range of 65,000-70,000 tons (Annual Report 2015-2016, 2016). The identified uranium resource is adequate for at least 150 years for any foreseeable growth scenario of nuclear power even if the uranium is used in 'open' fuel cycle on once-through basis. If all conventional and unconventional uranium resources are used in 'closed' fuel cycle using FBRs, then the resource will last tens of thousands of years.

The major challenge of nuclear power is radiological safety and back end of the fuel cycle. Natural uranium and thorium, the basic raw materials for nuclear fuel are mildly radioactivity and do not pose any serious hazard from external radiation. The fission products,plutonium and its isotopes and minor actinides (MA:N, Am & Cm) are highly radioactive and health hazardous and are required to be fully contained and handled in leak tight and shielded glove boxes or hot cells using remote and automated machineries and equipment. The fissile isotopes, U235, Pu239 and U233 and even some of the MA isotopes have very low critical mass (10-100 kg) and are dual use (civil and weapon) materials. Hence proper safeguards and proliferation-resistance practices are required to be in place to avoid clandestine diversion of fertile and fissile materials for non-peaceful purpose. These materials are also associated with criticality hazard for which real time accounting is necessary to avoid any criticality accident. Safety, Security and Safeguards are of paramount importance in nuclear reactor and fuel cycle technology.

Nuclear electricity generation in India started in 1969 with the commissioning of two BWRs of 200 MWe each, in collaboration with General Electric (GE) USA. These reactors use imported low enriched uranium (U235 enrichments: 1.6%, 2.1% & 2.66%) in the form of zircaloy 2 clad UO2 fuel rods that are clustered into 6 x 6 square fuel assemblies. The 2 BWRs are under IAEA safeguards and are still in operation at a de-rated capacity of 160 MWe each.

However, from the inception of the nuclear power program in India in the 1960, great emphasis has been given to self-reliance and indigenization. Accordingly, based on India's limited and low grade uranium resources (0.03-0.06% U3O8) but vast thorium deposits, a three stage nuclear power program, linking natural uranium (0.7% U235) -fueled PHWR in stage 1, plutonium (mainly Pu239) -based FBR in stage 2, using U238 and Th232 blankets and self-sustaining Th232 – U233 breeder in stage 3, was chalked out. India initiated construction of two PHWR 220 MWe units at Rajasthan Atomic Power Station (RAPS 1 & 2), at Rawathbhata, in collaboration with Atomic Energy of Canada Limited (AECL) in the late

1960s. Both RAPS 1 and 2 are under IAEA safeguards. RAPS 1 was commissioned in 1972 jointly by AECL and NPCIL. RAPS 2 was delayed and commissioned in 1982, mainly through the indigenous efforts of NPCIL because after India conducted the Peaceful Nuclear Explosion (PNE) in May 1974. Canada, USA and several other developed countries, discontinued nuclear collaboration with India, which is also not a signatory to the international Nuclear Non-Proliferation Treaty (NPT). In May 1998, India tested several nuclear devices and announced its nuclear weapon capability. Thereafter, the country was excluded from trade in nuclear plant, equipment or materials.

PHWR is the backbone of the indigenous nuclear power program in India that is underway for more than four decades. The country has achieved industrial maturity in PHWR and related technologies namely, UO2 fuel, zirconium sponge and zirconium alloy components and heavy water. After RAPS 1 and 2, NPCIL has constructed 14 PHWR 220 and 2 PHWR 540 MWe units with progressive improvement in design and safety features. However, the trade ban and inadequate indigenous source of natural uranium resulted in significant slowing down of the civil nuclear power program.

Fortunately, based on India's impeccable records in nuclear non-proliferation in import and exports of Special Nuclear Material (SNM) and excellent cooperation with IAEA in issues related to safeguards and safety, in the last quarter of 2008, the US Congress, IAEA and the Nuclear Supplier's Group (NSG) paved the way for India to have access to international uranium and reactor technology. From the year 2009 onwards, India started negotiations with reputable reactor vendors like Rosatom, Areva, Westinghouse and General Electric for setting up several Gen III + LWR parks jointly, with the understanding that except for a few critical components, most of the plants will be manufactured in India, thereby reducing the capital cost of the plant significantly. These vendors have now been allotted coastal sites. Pre-project activities and financial negotiations are underway. The LWRs will come with life time guarantee of supply of finished fuel assemblies. The vendors have also agreed to give the rights of reprocessing of spent fuel to India.

India will be entering the second stage of its nuclear power program with the commissioning of PFBR 500 in 2016. Austenitic stainless steel clad (type D9), mixed uranium plutonium oxide (MOX) fuel, containing 20-25% PuO2, is the reference fuel for PFBR and most of the demonstration, prototype and commercial sodium cooled FBRs constructed and operated in the world. Two additional FBR 600 MWe units have been ear marked alongside PFBR 500. The site development activities for the two FBR 600 units are underway at Kalpakkam. These reactors will also use MOX fuel. The FBR Park at Kalpakkam will also have an integrated and co-located spent FBR fuel reprocessing plant and an industrial facility for fabrication of MOXfuel.

3. NUCLEAR FUEL CYCLE ACTIVITIES IN INDIA

Nuclear power reactor and related nuclear fuel cycle technology go hand in hand. Long term sustainability of nuclear power will be possible only if nuclear electricity is economic and affordable and nuclear power reactors and fuel cycle facilities are safe, secured and proliferation-resistant and the highly radioactive and health-hazardous waste from the back end is properly managed, immobilized and kept ready for permanent disposal in deep underground geologically stable repository.

The 3-stage nuclear power program in India is being slightly modified as shown in Fig. 3. The first stage will now consist of indigenous PHWR 220, 540 and 700 MWe units fuelled with indigenous and imported natural uranium and Gen III + LWRs built in collaboration with reputable overseas reactor vendors with guaranteed life time supply of zirconium alloy clad enriched uranium oxidefuel. The U235 content in spent LWR fuel is in the range of 0.8 to 1.2% which is higher than that in natural uranium (0.7% U235). Hence, the Reprocessed Uranium (RU) from spent LWR fuel could be recycled in PHWRs. In the second stage, the plutonium from PHWRs and LWRs will be recycled in sodium cooled FBRs, in the form of stainless steel (type D9 or HT9) or oxide dispersion strengthened (ODS) steel clad mixed uranium plutonium ceramic or metallic fuel containing 15-25% plutonium. The uranium in FBR fuel could be Depleted Uranium (DU: < 0.7% U235) from the tailings of U235 enrichment plant or Reprocessed Depleted Uranium (RDU) from spent PHWR fuel. DU and RDU will also be used as blanket material in FBRs. The FBRs will produce more plutonium from U238 in fuel core and blanket than plutonium consumed in fuel. Thus, multiple recycling of Pu with DU and RDU in FBRs will enable at least 60% utilization of natural uranium resources which is otherwise <1% if plutonium is recycled in thermal reactor. At a much later date (way beyond 2050), thorium could be used a blanket to breed U233 for the third stage.

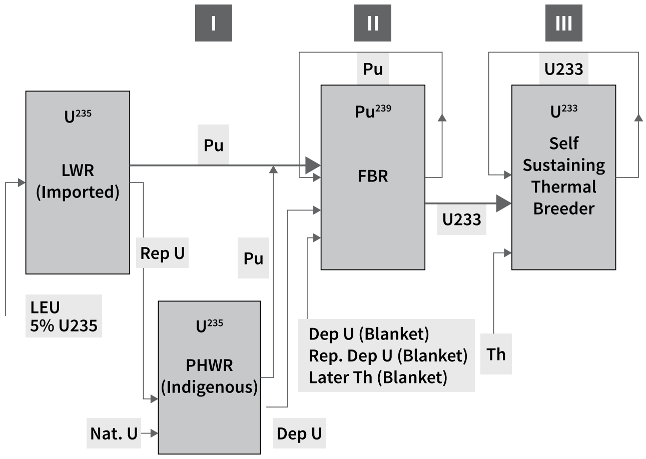


FIGURE 3. Closed nuclear fuel cycle in India, linking imported LWRs & indigenous PHWRs in stage I with FBRs in stage II and Th232-U233 thermal breeders in stage III

4. FRONT END OF URANIUM FUEL CYCLE

According to the latest update of Atomic Minerals Directorate of exploration and research (AMD) , Hyderabad, India has modest reserves of some 2,14,000 tons of identified conventional uranium resources which are of very low grade (0.03-0.06% U3O8) (Ganguly & Jayaraj, 2004). The vein type deposits in Singhbhum district of Jharkhand state are being mined and milled by Uranium Corporation of India Limited (UCIL) for more than four decades and have so far been the main source of indigenous uranium supply. Other vein type deposits at Gogi, Karnataka and Rohil, Rajasthan will be exploited in coming years. In recent years, uranium mine and mill have started operation at Cuddapah, Andhra Pradesh where huge stratabounduranium reserves (>100,000 tons U3O8) have been located. The sandstone type deposit at Meghalaya state has so far been the highest-grade Uranium ore (0.1-0.2% U3O8 average) but is yet to be exploited. The unconformity type deposits in northern Cuddapah district are being developed.

At the Singhbhum district, the uranium mines at Jaduguda, Bhatin, Narwapahar and Bagjata feed the uranium mill at Jaduguda. The Turamdih, Banduhurang (the only open cut uranium mine in India) and Mohuldih mines at Singbhum feed the Turamdih mill. At the Jaduguda and Turamdih mill the crushed and milled uranium ore is leached with sulfuric acid followed by purification using Ion Exchange (IX) resins and precipitation of UOC as magnesium diuranate (MDU) and uranium peroxide. The uranium ore from Tummalapallemine in south Cuddupah is subjected to alkali leaching because of high carbonate content in ore. High pressure, high temperature leaching technique has been developed, followed by ion exchange purification and precipitation of UOC as sodium diuranate (SDU).

5. MANUFACTURING OF ZIRCALOY CLAD UO2 FUEL ASSEMBLY (BUNDLES) AT NFC, HYDERABAD

Since the early 1970s, the Nuclear Fuel Complex (NFC) at Hyderabad has been manufacturing zircaloy (an alloy of Zr and ~ 1.5% Sn with traces of Fe, Cr and Ni; zircaloy 4 is nickel-free) clad natural UO2 fuel bundles for the PHWR units. The starting materials till 2009 have been: i) UOC from the UCIL uranium mills at Jaduguda and Turamdih and ii) Zircon (zirconium silicate) sand mined by Indian Rare Earths Limited (IREL) from the beach sands in Kerala, Tamil Nadu and Orissa states. Since 2009, NFC has been importing natural UO2 pellets from JSC-TVEL (Russia) and UOC from Kazatomprom (Kazakhstan). Areva, France has also supplied one consignment of natural UOC. In 2015, Cameco Corporation, Canada supplied the first consignment of natural UOC. Negotiations are underway to import natural UOC from Uzbekistan, Namibia and Australia. So far, in 10 PHWR 220-unit fuel bundles manufactured from imported UOC or UO2 pellets have been used, namely, the 6 units at RAPS and the two units each at Narora Atomic Power Station (NAPS) and Kakrapar Atomic Power Station (KAPS). These reactors have been placed under IAEA safeguards. Indigenous natural uranium is used to fuel the two PHWR 540 at Tarapur (TAPS 3 & 4), the 4 units of PHWR 220 at Kaiga Atomic Power Station (KGS 1-4) and the two PHWR 220 at Madras Atomic Power Station (MAPS). In coming years, some or all upcoming PHWR 700 units are also likely to use imported UOC or UO2 pellets and will be also placed under IAEA safeguards. In recent years, NFC has been receiving UOC in the form of SDU from Tummalapalle.

The UOC from indigenous and overseas sources are refined and processed in different plants. The plants using imported uranium are under IAEA safeguards. The UOC is dissolved in nitric acid and purified by solvent extraction using tri butyl phosphate in kerosene as solvent in a series of mixer-settlers. The purified uranium nitrate solution is then converted to ammonium diuranate (ADU) and precipitated. The ADU is next converted to fine and sinterable UO2 powder by sequential air-calcination, hydrogen reduction and stabilization. The UO2 powder is then granulated and cold-compacted into cylindrical pellets which are then sintered at high temperature (~ 1700 C) in continuous pusher type sintering furnace in hydrogen atmosphere to form high density UO2 pellets. The pellets are centerless ground to the desired diameter, stacked into fuel columns and loaded in zircaloy 4 cladding tubes with bearing and spacer pad appendages on outer surface and graphite coating on inner surface. The end caps of the fuel elements are resistance-welded. Next the fuel pins are assembled in circular configuration as 19-fuel element bundles for PHWR 220 and 37-element bundles for PHWR 540/700. Figure 4. shows the major steps in fabrication and quality control of PHWR fuel at NFC. typical fuel bundles/ assemblies for PHWR 220 and PHWR 540/700 (Raj, Chellapandi, & Rao, 2014). The quality and quantity of PHWR fuel at NFC has significantly improved over the years and in 2014-2015, NFC became the largest PHWR fuel producing plant in the world with an annual production of ~ 1250 tons. Figure 3. shows the fuel elements for PHWR 220 and PHWR 540/700 units in India.

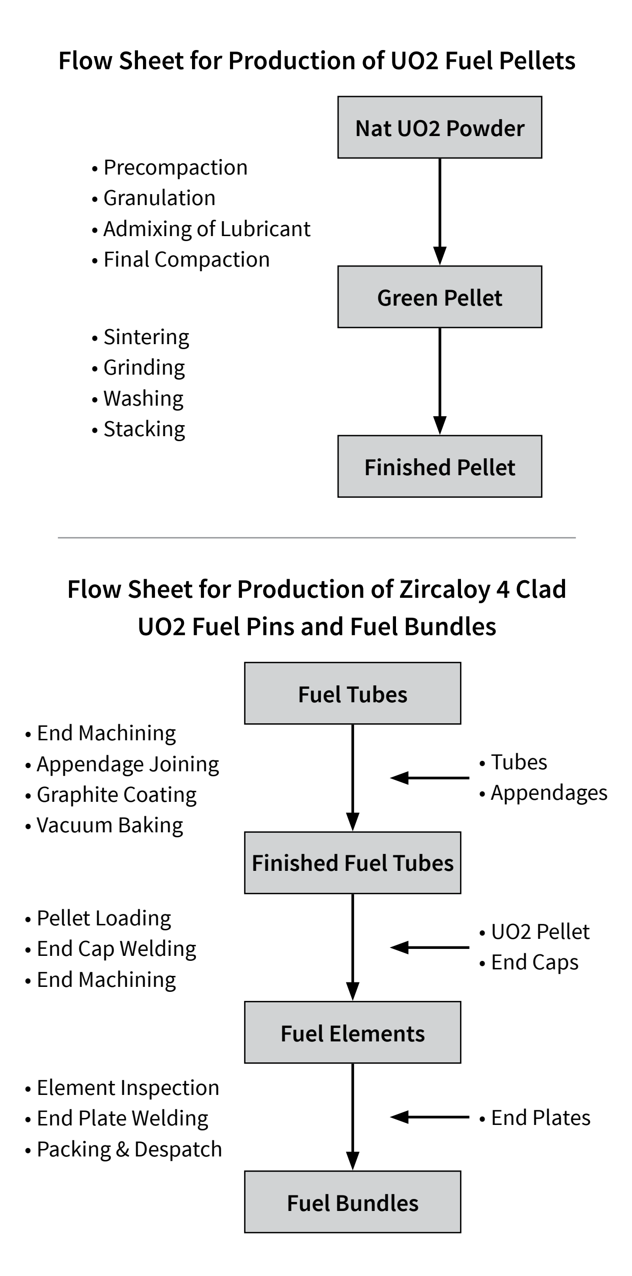
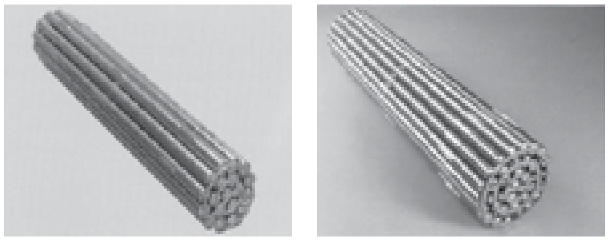


FIGURE 4. Major Process Steps Followed Innfc, Hyderabad For Manufacturing 19 - Pin Phwr 220mwe & 37 - Pin Phwr 540/700 Mwe Fuel Bundles

NFC has also been manufacturing Zircaloy 2 clad enriched UO2 fuel assemblies for the two BWR 160 units. Initially, enriched uranium containing 1.6%, 2-1% and 2.66% U235 was imported from USA, France and China in the form of UF6, but since 2002, JSC-TVEL, Russia has been supplying enriched UO2 pellets for TAPS 1 & 2. Figure 3. shows the 6x6 BWR 160 fuel assembly that is being routinely manufactured at NFC (Hemantha Rao, 2005).



16 x PHWR 220 MWe in Operation

- 19-Element Fuel Bundles for PHWR 220 MWe
- 328 Welds per Fuel Bundle (FB)
- Resistance Welding for All Welds
- Contains ~ 15.2 kg UO2 Fuel Pellets
- Each Fuel Assembly Generates 700,000 kWh
- PHWR 220 MWe Contains 12 x 306 = 3672 FBs
- No. of welds in PHWR 220 MWe Fuel Core

2 x PHWR 540 MWe in Operation

4 x PHWR 700 MWe Under Construction

- 37-Element Fuel Bundles for PHWR l540/700 MWe
- 622 Welds per Fuel Bundle (FB)
- Resistance Welding for All Welds
- Contains ~ 22.5 kg UO2 Fuel Pellets
- Each Fuel Assembly Generates 1,100,000 kWh
- PHWR 540/700 MWe Contains 12 x 392 = 4704 FBs
- No. of welds in PHWR 540/700 MWe Fuel Core: 4704 x 392 = 1,843968

ALL SUBSEQUENT PHWR UNITS IN INDIA WILL BE OF PHWR 700 MWE

FIGURE 5. PHWR 220 and PHWR 540/700 Fuel Assemblies Manufactured at NFC routinely

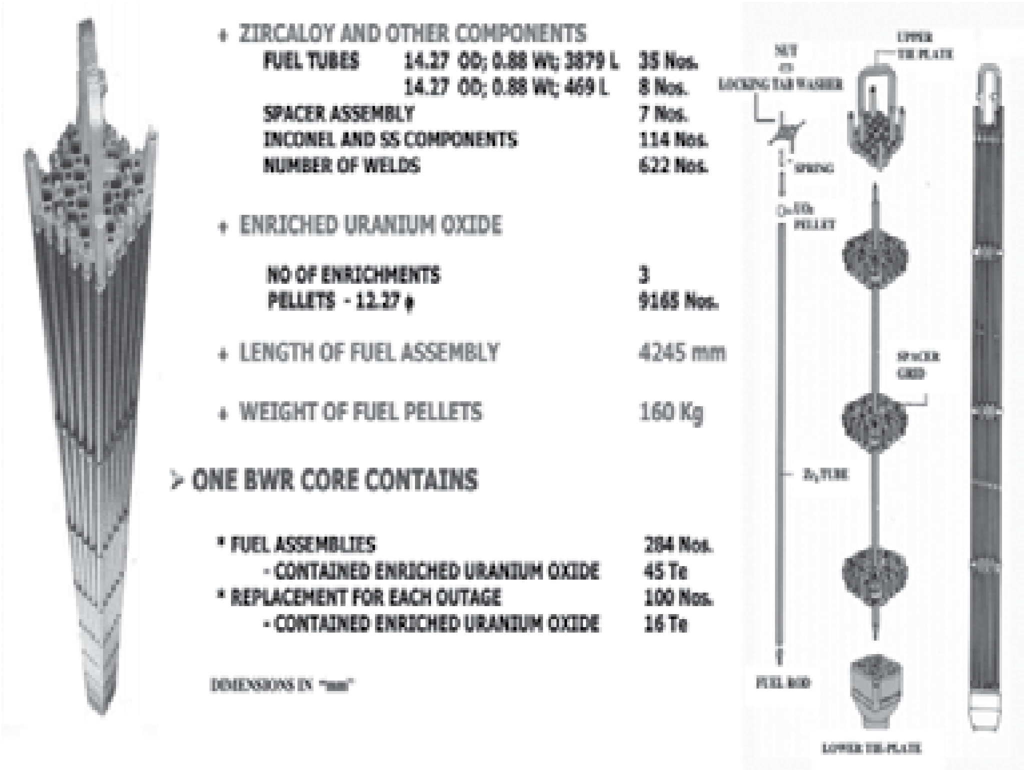


FIGURE 6. A Typical 6 X 6 BWR 160 Mwe Fuel Assembly Manufactured At NFC For Taps 1 & 2

6. BACK END OF NUCLEAR FUEL CYCLE AND MANUFACTURING OF FAST REACTOR FUEL

The growth and long term sustainability of nuclear power in India will depend on early introduction of many sodium cooled FBRs and multiple recycling of uranium and plutonium in these reactors. At a later date efforts should be made to separate the minor actinides (Np, Am & Cm) from spent fuel and use them as fissile and fertile materials in FBRs. Thus, the quantity and volume of radioactivity and decay heat in high level waste for permanent disposal in deep underground repository will be significantly reduced.

The first spent fuel reprocessing plant in India was set up in 1965 at the Bhabha Atomic Research Centre (BARC) at Mumbai, mainly to reprocess spent aluminum clad uranium metal fuel from research reactor. The classical PUREX (plutonium uranium refining by solvent extraction) was adapted. Based on the successful experience at BARC, Mumbai, three reprocessing plants (two at Tarapur and one at Kalpakkam) were set up to reprocess zircaloy clad UO2 spent fuel from water cooled reactors. Today, India has an annual reprocessing capacity of 330 tons uranium. The three plants are not under IAEA safeguards. The plutonium from these plants are being utilized for manufacturing MOX fuels containing 20-25% PuO2 at the MOX plant at Tarapur.

Figure 7. shows the PFBR 500 core and some details of the MOX fuel assembly (Kamath, Anatharamanand, & Purushotham, 2000). Manufacturing of the MOX fuel, with RDU oxide axial blanket at both ends of the fuel column, for the first core of PFBR 500 is underway at the MOX plant at Tarapur. The stainless-steel cladding tubes, hexcans and other SS hardware and SS clad RDU pellets for PFBR blanket assemblies have been fabricated at NFC, Hyderabad. The first few reload MOX fuel for PFBR 500 will be manufactured at the Tarapur MOX plant till the integrated MOX facility at the Kalpakkam FBR park is commissioned.

The annular MOX fuel pellets for PFBR are manufactured by the classical 'powder- pellet' route starting with UO2 and PuO2 powders. The oxide powders are co milled in an attritor to ensure excellent UO2 and PuO2 micro-homogeneity, cold-pelletized in rotary compaction press and sintered at 1650 C in Ar-H2 atmosphere in batch type sintering furnace (Kumar, 2013),(Ganguly & Rajaram, 2013). The MOX pellets are subjected to dry centre less grinding to the specified diameter, inspected, stacked and loaded in SS(D9) cladding tubes and the end plugs are welded by Tungsten Inert Gas (TIG).

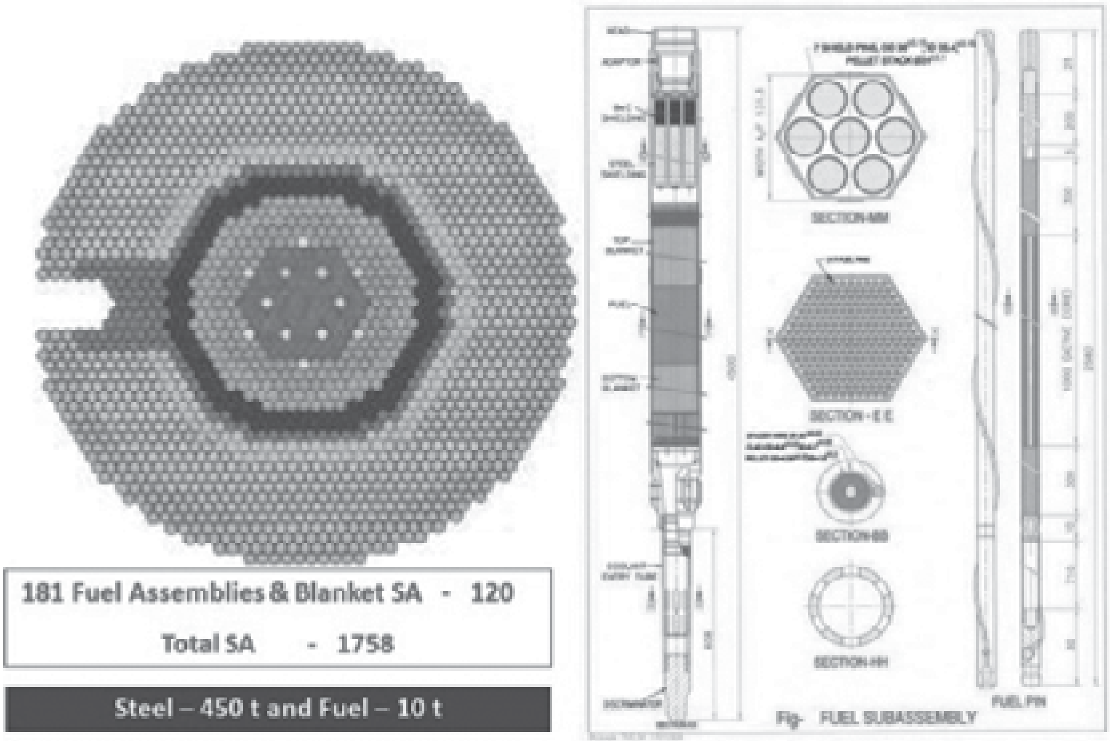


FIGURE 7. PFBR 500 Core With 181 MOX Fuel Assemblies In Centre Surrounded By 120 RDU Oxide Blanket Assemblies

7. EXPLORING POSSIBILITY OF IMPORTING PLUTONIUM

The key to the commercial success of FBRs in India would be availability of plutonium, on time, and development of FBR fuel that will perform satisfactorily to high burn up (>100,000 MWD/ton heavy metal – preferably up to 200,000 MWD/tom HM), breed plutonium efficiently and will be easy to reprocess, re-fabricate and recycle in FBRs.

Regarding availability of plutonium, India should explore the possibility of importing plutonium from countries like USA, Russia and UK which have several hundred tons of separated plutonium of either weapon grade (>93% Pu239) or civilian grade and launch several safeguarded and integrated FBR parks, each having 4 to 6 FBRs and co-located facilities for reprocessing and re-fabrication of FBR fuels (Megatons to Megawatts program concludes, 2013). The project should follow the successful “megaton to megawatt” joint mission of USA and Russia during 1993-2013. Under this mission, 500 tons of weapon grade high enriched uranium (HEU: >20% U235) containing >90% U235 dismantled from nuclear war heads in Russia was down blended to low enriched uranium (LEU < 20% U235) containing < 5% U235 that was used as fuel in LWRs in USA (Chang, 2007).

Metallic fuel is considered as advanced fuel for sodium cooled FBRs because of much higher breeding ratio and nearly seven times higher thermal conductivity compared to the reference mixed uranium plutonium oxide fuel. Metallic fuel of composition U-20 Pu-10 Zr, sodium bonded and clad with ferritic SS HT-9 or ODS, have demonstrated inherent and passive safety and excellent performance in EBR II in USA. Metallic fuel pins are easy to manufacture by induction melting followed by injection casting [12]. Spent metallic fuel is amenable to pyro-electrolytic refining which is simpler than the classical PUREX aqueous route. India should seriously consider adapting the Integrated Fast Reactor (IFR) model for large scale implementation of FBRs with metallic fuel, preferably in collaboration with USA.

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