OPTIMIZING INVENTORY MANAGEMENT IN POWER PLANT OPERATIONS: A COMPREHENSIVE ANALYSIS OF SELECTIVE CONTROL POLICIES

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Abstract - ***Purpose:*** *This study critically evaluates the application of selective inventory control techniques within power plant operations. It focuses on optimizing inventory levels, reducing operational costs, and ensuring the continuous availability of essential spares. By employing well-established techniques such as ABC, VED, XYZ, FSN, HML, and SDE, the study aims to provide power plant operators with practical insights for improving inventory management and enhancing overall operational efficiency.*

Methodology: *Each technique is analyzed based on factors like consumption value, criticality, movement dynamics, inventory value, and procurement challenges, with a focus on their applicability to power plants.*

Results: *The findings demonstrate how power utilities can apply these techniques to prioritize high-value and critical items, reduce carrying costs, and avoid stockouts. Practical recommendations for tailoring these methods to power plant needs are provided.*

Key Words: ABC, FSN, Inventory management, Selective control, VED, XYZ, Power plant operations.

1.INTRODUCTION

Inventory management stands as a cornerstone of operational efficiency and profitability in businesses across various sectors, none more critical than in power utilities where thousands of spares dictate operational continuity/efficiency. It is crucial for business success, as it directly impacts customer satisfaction, operational expenditures, and overall financial performance [1]. One significant aspect of effective inventory management is the application of selective inventory control techniques. These techniques allow businesses to optimize their inventory levels, reduce carrying costs, and guarantee timely availability of the required products. If selective control techniques are not adopted, a situation may arise where the control cost exceeds the value of any benefit arising out of control action. Moreover, in the absence of selective control techniques, the control efforts can become diffused and desultory that its very purpose is lost [2].

This study focuses on exploring these selective inventory control techniques within the context of power plant operations, which require thousands of spares, making inventory control particularly complex [3]. In power plants, managing a large size store can be a challenging endeavor due to the diverse characteristics of its items like:

1. Varying annual consumption values, ranging from significant to negligible.
2. Diverse movement frequencies, with some items experiencing high turnover and others remaining stagnant for years together.
3. Varying sourcing origins, including imported and domestically available items.
4. Different levels of operational importance, from vital components crucial for uninterrupted operations of organization to desirable items with minimal impact on operations, except some small inconvenience or criticism (item like tumbler glass or a stationery item).
5. Varying unit rates, including items like a small bolt or nut to a rotor, which may be very expensive.

Given these challenges, implementing selective control techniques becomes vital to maintain an efficient inventory system. Each technique, such as ABC, VED, XYZ, FSN, HML, and SDE, offers a unique method for categorizing and controlling inventory based on different factors like consumption value, criticality, and procurement challenges. However, power plant operations require a tailored approach to applying these techniques effectively.

This study aims to not only explore these techniques but also critically evaluate their applicability to power plant operations. Through this evaluation, we propose specific, actionable recommendations for power plant operators to enhance their inventory management practices. By applying these established techniques, power plants can optimize inventory levels, reduce operational costs, and improve the availability of critical spare parts, ultimately leading to greater operational efficiency and reliability.

Table 1 below summarizes the selective control techniques discussed in this paper and their key criteria.

Table 1: Selective Control Techniques

Classification	Criteria
ABC (also known as Always Better Control)	Annual consumption value of items
VED (Vital, Essential & Desirable)	Criticality of items i.e. non-availability of items when required shall affect operations to what extent.
XYZ	Value of items in inventory at a given time (Financial Year Closing).
FSN (Fast, Slow & Non-Moving)	Movement i.e., issues from stores (velocity at which items move).
HML (High, Medium & Low Unit Rates)	Unit Price of items (price of one piece).
SDE (Scarce, Difficult & Easy)	Purchasing issues with regards to availability in market.

2. ABC SELECTIVE TECHNIQUE

In power plant operations, where thousands of items are maintained in stock, adopting a selective approach to inventory control is critical. ABC analysis is one of the most effective techniques for managing inventories by prioritizing items based on their annual consumption value. This helps power plants focus control efforts on the most economically significant items, which is essential for ensuring operational efficiency and reducing costs.

2.1 Categorization of Inventory Items into ABC

When analyzing all the store items in an inventory based on their annual consumption value of each (in rupee or dollars), it becomes evident that approximately 10-12% items account for 65-70% of annual consumption value, 20% of the items make up 15-20% of annual consumption value, while the remaining 70-75% items contribute to just 10-15% of the total annual consumption value. ABC analysis divides inventory into three categories: the small number of high consumption value items are classified as A items, the medium consumption value items as B items, and the large number of low consumption value items as C items [4, 5, 6]. It is important to note that ABC analysis is based on annual consumption value, not on unit cost of items, and is not based on importance of the item, as all items in stock are considered important. This categorization enables power plants to apply more stringent control measures to A items, which are few but have high consumption value, while C items, being numerous but of lower consumption value, require less oversight (see Table 2)

Table 2: ABC Classification

Category	Approx. number of items	Approx. annual consumption
A	10-15%	70-75%
B	15-20%	15-20%
C	70-75%	10-15%

Example: In a power plant, high consumption items like electric bulbs (categorized as A items) require tighter control despite their low unit cost (Rs.10). Conversely, consider an expensive machine that needs to be installed on a foundation, but the job could not be completed since four foundation bolts are missing. These bolts might be classified as C items, because their annual consumption value is relatively low, not exceeding a thousand rupees. However, they are critically important because, without them, the machine cannot be installed.

2.2 Effect of ABC Analysis on Inventory Policies

ABC analysis allows power plants to allocate their resources effectively by focusing on items that need the most attention. Category A items require tight control, with accurate demand forecasting, scheduled deliveries, and frequent reviews, category B items are managed with moderate control measures and category C items may be managed with relaxed control, larger safety stocks, and less frequent orders. This prioritization helps power plants maintain critical spare parts for continuous operations without tying up excessive capital in lower-value items.

2.3 Fixing Inventory Policies in ABC

The method of fixing inventory policies for each category in ABC is outlined in Table 3.

Table 3: Methods of fixing inventory policies

Category	Control level	Order frequency	Safety stock
A	Tight Control	Frequent, small quantities	Low
B	Moderate Control	Balanced	Medium
C	Least Control	Bulk ordering	Large

This structured approach ensures that the most critical and high-value items are managed closely, while less important items are handled more efficiently, freeing up resources for more significant aspects of the inventory.

2.3 Advantages of ABC Analysis

The advantages of applying ABC analysis in power plant operations include:

1. Prioritization of critical items: Ensuring that resources are focused on high-value, high-impact inventory.
2. Cost savings: Reduced carrying and ordering costs by optimizing inventory levels for each category.
3. Improved resource allocation: By concentrating efforts on managing A and B items, the power plant can enhance operational efficiency.
4. Reduced stockouts: Better inventory management reduces the likelihood of production delays due to unavailability of critical items.
5. Streamlined processes: Reduced administrative and material handling efforts for low-value C items.

3. VED SELECTIVE TECHNIQUE

While ABC analysis focuses on categorizing items based on annual consumption value, VED analysis categorizes inventory items based on their criticality to operations. In power plants, where operational continuity and safety are paramount, VED analysis is crucial for prioritizing items that directly impact performance [7].

Vital (V): These are critical items, the unavailability of which would cause the equipment to become inoperative or unsafe to use. Stockouts of vital items could lead to significant downtime, financial losses, or a complete shutdown of the plant.

Essential (E): These items are important but not immediately critical. A stockout would reduce equipment performance and could lead to costly procurement or stoppage of work. If not addressed in a timely manner, they may become vital.

Desirable (D): These items are non-essential for immediate operations and their stockout would only cause minor disruptions or inconveniences.

3.1 Applications of VED in Power Plant Operations

In power plants, VED analysis is often conducted in conjunction with equipment classification using the VEIN framework. The combination of these classifications helps identify critical spare parts and equipment, ensuring that resources are focused on maintaining the most important aspects of plant operations. This mapping of vital spares with vital equipment ensures that power generation is not disrupted due to the unavailability of critical parts.

This combination is crucial for identifying the most critical spare parts, non-availability of which shall result in immediate loss of production, impacting power generation. This process, also known as mapping of vital and critical spares with vital equipment, ensures that resources are effectively allocated to maintain the smooth functioning of essential equipment in power plants. The VEIN equipment classification in a power plant or any process plant is given in Table 4.

Table 4: VEIN Classification of Equipment

Type of Equipment	Description
Vital	Equipment failure immediately halts power generation or creates unsafe conditions.
Essential	Equipment failure may not stop generation immediately but risks future losses if not repaired.
Important	Failure disrupts non-critical operations, like auxiliary units.
Normal	Failure causes minor or no disruption, such as office equipment.

3.2 Importance of VED and VEIN Analysis

The combination of VED for spare parts and VEIN for equipment is vital in power plants for maintaining operational efficiency and minimizing downtime. Critical items, such as Vital spares for Vital equipment (VV items), require constant monitoring, higher safety stocks, and frequent review by senior management to avoid operational interruptions. Effective VED analysis also helps power plant operators:

1. **Focus on critical spares:** Ensuring that items essential for plant safety and operation are always available.
2. **Optimize inventory levels:** By prioritizing vital and essential items, power plants can reduce unnecessary inventory costs associated with overstocking less critical items.
3. **Reduce downtime:** Ensuring critical spares are available minimizes the risk of extended downtime due to unavailability.
4. **Improved resource allocation:** Focus efforts on managing the most critical parts to optimize operational efficiency.

The classification of items into Vital, Essential, and Desirable categories should be done carefully and in consultation with maintenance and operational experts. Misclassification could lead to excessive safety stocks, increasing inventory costs unnecessarily. Careful evaluation of factors such as the item's role in operations, its criticality, and the urgency for replacement is essential for successful VED analysis.

4. COMBINATION OF ABC AND VED

In power plant operations, the conventional ABC method is not always sufficient for spare parts management due to the criticality of certain parts, regardless of their cost. A low-cost C category item, such as a bolt, may be critical to plant operations, making VED analysis more relevant. The VED (Vital, Essential, Desirable) classification prioritizes parts based on their impact on operations rather than cost, making it a more appropriate technique for spare parts management in power utilities. Therefore, the primary focus of spare part management is VED analysis [8]. Table 5 outlines the recommended stock levels based on the criticality and category of spare parts.

Table 5: Stock level recommendations in ABC/VED

Category	Vital	Essential	Desirable
A	Medium stock	Low stock	Very low stock
B	High stock	Medium stock	Low stock
C	Very high stock	High stock	Medium stock

4.1 Safety Stock and Buffer Stock

Safety/buffer stock serves as a necessary cushion during periods of higher consumption or when the normal delivery period is exceeded or both. Thus, the main objective of safety stock shall be to absorb variability (due to uncertainties of consumption and lead-times for replenishment supplies) and mitigate the risk of stock-out (situation when item is required but is not available in stock). Longer the lead-times, the greater shall be variability of demand and higher safety stock shall be needed [9]. If there were no variation in consumption as well as length of lead–time, there would be no need for safety stock. A fixed quantity of material may be ordered at a fixed interval [10].

4.2 Service Level

Service level refers to the percentage of material requests fulfilled without delay. High service levels are desirable for Vital items (VED classification) to prevent downtime, while lower service levels are acceptable for less critical items. Achieving a balance between high service levels for critical items and efficient inventory turnover is crucial for optimizing resources in power plants.

Table 6 demonstrates a strategy to balance the availability of spare parts against their criticality and cost. The most critical and low-cost items have the highest service levels to ensure they are always available, whereas less critical and high-cost items have lower service levels to reduce inventory holding costs. This approach optimizes resource allocation and ensures that vital operations are supported by the necessary spare parts.

Table 6: Statistical table of service level

Based on criticality of spares	Based on Annual Consumption Value			
	Category	A	B	C
	V	85% service level	95% service level	99.9% service level
	E	75% service level	85% service level	95% service level
	D	50% service level	75% service level	80% service level

4.3 Summary of ABC/VED Control Action

Combining ABC and VED classification helps in reallocate scarce resources from non-critical areas to critical areas, balancing inventory and optimizing resources utilization [11, 12]. The control action can be summarized as:

1. Vital, low-cost spares should be held in higher stock levels to avoid costly downtime.
2. Desirable, high-cost spares should have minimal stock to reduce carrying costs.
3. Critical, frequently used spares should have decentralized stock for quick access, with generous safety stock to minimize the risk of outages.

5. XYZ SELECTIVE TECHNIQUE

XYZ analysis classifies inventory based on the value of stock at a given point in time, typically at the close of the financial year. Unlike ABC analysis, which focuses on consumption value over a specific period, XYZ analysis accounts for all items held in stock, regardless of their usage during that period. This classification helps power plant operators assess the distribution of inventory value and manage high-value items effectively [13]. In XYZ analysis:

X items: High inventory value, typically accounting for 70-75% of total stock value but representing only 8-10% of total items.

Y items: Medium inventory value, making up 15-20% of total stock value.

Z items: Low inventory value, representing the bulk of the inventory in terms of items (65-70%) but only 10-15% of the total stock value.

5.1 Summary of ABC/XYZ Control Action

When used in conjunction with ABC classification, XYZ analysis becomes an effective tool for controlling inventory costs, especially for high-value items. Power plant operators can focus control efforts on X items with high inventory value while balancing the cost of holding A, B, and C items based on their consumption value [13], as illustrated in Table 7.

Table 7: Control matrix of XYZ/ABC

Category	X	Y	Z
A	Critical analysis to reduce stocks. Frequently ordered in small quantities or arrange staggered quantities.	Attempts to reduce stock to Z category i.e. as low as possible.	Items are well within control, a happy situation.
B	Review consumption v/s stock frequently to optimize inventory.	No further action is needed as items are generally under control.	Review twice a year.
C	Dispose of surplus stock held for more than 6 years (stock value > Rs. 3 Lacs and consumption < Rs. 50000).	Control can be lightened.	Review annually.

6. HML SELECTIVE TECHNIQUE

HML analysis classifies items based on their unit price (value per item) rather than their annual consumption or stock value. This technique is particularly useful for identifying high-cost items that require special attention in terms of procurement, storage, and handling [14].

The HML technique is especially relevant in power plants for managing high-cost spare parts, such as turbine blades, transformers, or other critical components that must be handled with extra care due to their value. The steps of HML analysis are as follows:

1. Items are listed in descending order of magnitude of unit rate.
2. High, medium and low-rate limits are determined based on unit rate. For instance, it may be decided that items with unit value of Rs.10,00,000 and above are high unit items and up to Rs. 50,000 as low unit rate items and intermediary items as medium unit value items.
3. On this basis, management may delegate the authority of procurement at various levels.
4. Authority to requisition of H category items may be delegated suitably to higher level of management.
5. Storing policies including security in stores may also be decided keeping in view this classification. Additional care is ensured in handling and preservation of H category items/spares including frequency of stock-taking.
6. Meticulous planning and attention is ensured while purchasing H category items/spares including delegating the authority of procurement at various levels.

HML technique helps in identification of items/spares for the purpose of pooling, if similar equipment/units are at different location so that not only their inventory is optimized but also can be transferred from one plant to another to meet emergency and minimize equipment downtime losses. This technique further facilitates the identification and capitalization of insurance spares [3].

7. FSN SELECTIVE TECHNIQUE

This classification is based on pattern of movement of items i.e. issues from stores (velocity at which items move from stores). Items are categorized as fast moving, slow-moving and non-moving items based on their average stay in stores and their consumption rate [15]. This classification helps in managing the flow of inventory by focusing on how frequently items are issued and their average stay in storage.

- **Fast-moving (F):** Items with frequent issues from stores, indicating high demand and shorter storage times.
- **Slow-moving (S):** Items with fewer issues over a period, reflecting moderate demand.

- **Non-moving (N):** Items that have not been issued for a long time, often due to obsolescence or changes in technology or plant operations.

This classification is a very effective tool to control obsolescence and redundant inventory. By analyzing the reasons for non-movement of items, it addresses issues like change in technology or modification or renovation and modernization in plant/power station. When equipment is phased out, related items may not have any use in future. Efforts are made to find out alternative uses of these items but failing this, economical disposal shall be considered. Additionally, the items become non-moving due to change in specification. FSN helps to identify slow moving and non-moving items. Since spares by nature are slow moving as compared to materials other than spares different time period should be used as criteria to define fast moving and slow-moving items.

7.1 Combining FSN with XYZ Analysis

When used in combination with **XYZ analysis**, FSN provides a comprehensive approach to inventory control by addressing both movement patterns and inventory value [16]. This combined analysis helps power plant operators make informed decisions on stock levels, procurement, and disposal of surplus or obsolete items. The control matrix is given in Table 8.

Table 8: Control Matrix of FSN with XYZ

Category	F	S	N
X	Tight control, stop further procurement, review items in pipeline.	Reduce stock to low levels.	Immediate review of surplus/redundant items and arrange disposal.
Y	Normal control, as available stock is optimum, a happy situation.	Low stock level	Review and prioritize disposal.
Z	Increase stock to avoid stockouts.	Low stock level.	Review and dispose surplus items.

8. SDE SELECTIVE TECHNIQUE

SDE classification categorizes inventory items based on their purchasing difficulty and market availability:

Scarce (S): Items that are hard to obtain, often requiring international sourcing or long lead times. These items may have very few suppliers or may be difficult to manufacture.

Difficult (D): Items that are available but require extended sourcing efforts, either nationally or internationally, with longer delivery periods.

Easy (E): Standard, mass-produced items that are readily available from local or regional markets and can often be supplied ex-stock.

This classification is especially useful for power plants where the availability of critical spare parts can impact operations, and lead times for sourcing scarce or difficult items can cause significant delays.

8.1 SDE Control Action

For scarce and difficult-to-procure items that are high consumption (A class) and critical (Vital), it is essential to implement detailed planning, supported by a comprehensive market intelligence system. Inventory levels should be kept low, but rigorous control measures must be in place to prevent stockouts. Phased deliveries should be arranged with constant follow-up to ensure timely availability. Additionally, for certain high-value interchangeable spares, establishing a spares bank or pooling system can be considered to ensure availability across multiple plants. For high-value, slow-moving items that are non-critical, cost-reduction strategies such as developing alternate sources of supply, including import substitution, should be explored. Establishing spares pooling for such items can also help optimize resources. Initially, source development efforts should be focused on non-critical items, with successful strategies later applied to critical ones.

9. COMPARATIVE ANALYSIS OF INVENTORY CONTROL TECHNIQUES

Table 9 presents the comparative effectiveness in a clear, concise manner and provides specific insights on how each technique applies to power plant operations.

Table 9: Comparative Analysis of Inventory Control Techniques

Technique	Strengths	Weaknesses	Applicability to Power Plants
ABC	Prioritizes items by consumption value. Helps manage high-cost, high-consumption items.	May neglect low-cost but critical items. Does not account for operational criticality.	Best used for cost management and identifying high-consumption items. Needs to be combined with VED.
VED	Focuses on operational criticality. Ensures vital parts are always available.	Does not consider cost or consumption frequency. May lead to overstocking non-critical high-consumption items.	Crucial for ensuring availability of critical spares. Should be used with ABC for a balanced approach.
XYZ	Focuses on inventory value at a specific point. Helps identify and manage high-value stock.	May over prioritize high-value, low-movement items. Neglects fast-moving, low-value parts.	Ideal for managing high-value items in stock. Useful when combined with FSN to avoid overstocking.
FSN	Categorizes items by movement frequency. Helps manage fast-moving and non-moving items.	Doesn't account for cost or criticality. Over-prioritizes frequently moving low-value items.	Effective in controlling obsolescence and preventing overstock of non-moving items. Combines well with XYZ.
HML	Prioritizes items by unit cost. Focuses on high-cost items that need careful control.	May over-prioritize expensive but non-critical items. Ignores movement and criticality factors.	Best for managing high-cost, low-quantity items. Should be combined with VED and SDE for critical items.
SDE	Focuses on procurement challenges. Identifies scarce and difficult-to-source items.	Doesn't account for cost or movement. May lead to overstocking scarce but non-essential items.	Ideal for managing critical but hard-to-source parts. Best used for vital spares with long lead times.

10. CONCLUSION

In power plant operations, the availability of critical spare parts is essential for ensuring continuous and efficient performance. By employing a combination of selective inventory control techniques such as ABC, VED, XYZ, HML, FSN, and SDE, power plant operators can develop a robust and efficient inventory management system that not only reduces operational costs but also minimizes risks associated with stockouts, overstocking, and obsolescence. By integrating these techniques, power plants can optimize inventory levels, reduce carrying costs, and improve service levels, all while ensuring the availability of vital components.

In conclusion, the selective inventory control methods discussed in this paper offer power plant operators the tools necessary to manage their inventory effectively, ensuring operational continuity and financial sustainability. These techniques provide a balanced approach to managing both high-value and critical items, reducing the risk of operational disruptions while minimizing inventory costs. Future research and practical implementations could further explore the integration of predictive analytics and modern technologies to enhance the effectiveness of these traditional inventory management techniques.

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