Journal of Harbin Engineering University
ISSN: 1006-7043

Vol 45 No. 7
July 2024

Powering Tomorrow: Exploring Evolving Trends in Demand Side Management (DSM)

[1]R.F. Chidzonga, [2]Bakhe Nleya
[1]Mangosuthu University of Technology
Postal address: 511 Griffiths Mxenge Highway, Umlazi, KwaZulu-Natal,4031
[2]Durban University of Technology
Steve Biko Campus, Durban, KwaZulu-Natal,4001

Abstract. Many nations actively engage in renewable energy initiatives to mitigate environmental challenges stemming from the extensive reliance on hydrocarbons for electrical energy generation. Concurrently, there are efforts to reduce greenhouse gases such as carbon (CO_x), methane (CH_x), and nitrous (N_2O) oxides atmospheric concentrations.

However, traditional electrical grid infrastructures, often operating at or near full capacity, present socio-economic constraints in efforts that may be expanded to increase transmission capacities to cater to ever-growing demand. The growth of renewable energy like wind and solar power has led to a significant increase in electricity generation at the distribution level, necessitating the evolution of electricity grids into bi-directional networks known as virtual power plants or Smart Grids capable of transmitting both energy and information for efficient energy management.

As the energy landscape shifts towards decentralized generation and incorporates diverse energy market participants such as independent power producers and prosumers operating within local Smart Grids, the concept of Demand Side Management (DSM) emerges as a compelling strategy to effectively manage finite energy resources amidst escalating electricity demands, particularly within domestic settings. This article explores potential initiatives to enhance energy consumption efficiency within the context of the South African Energy landscape, which has grappled with well-documented and pervasive load-shedding incidents.

We summarize possible measures for the successful implementation of DSM, which span behavioural change, technological integration, data privacy, market structures, infrastructure limitations, socioeconomic disparities, regulatory barriers, and coordination among stakeholders. Overcoming hurdles will require holistic approaches of integrating technology, policy reform, consumer engagement, and stakeholder collaboration to maximize DSM's potential.

Key Words: DSM,

A. Introduction-Historical Perspectives

Until recently, the 20th-century legacy electrical grid network (Grid 1.0) comprising unidirectional generation, transmission, and distribution formed the backbone of an intricate system facilitating the reliable delivery of electricity to many downstream consumers.

Bulk power stations were located far from load centres. Ohmic energy losses accompanied the attendant negative impacts of GHE in the environment due to heavy reliance on nonrenewable sources for power generation.

These legacy networks are rapidly being transformed into more technologically advanced systems due to factors such as increased demand, network congestion, market liberalization, and the maturity of renewable energy technologies[1]. Generation is becoming more distributed and ubiquitous, particularly at the low voltage level.

In some countries for example, Denmark stands as a leading example with a significant contribution of renewable energy generation, accounting for about 81% of electricity demand in 2022[2]. With the current technological advancement, the notion of 100% renewable energy is becoming achievable, wherein renewables can always meet demand by aligning consumer hourly requirements with local renewable energy production,[3].

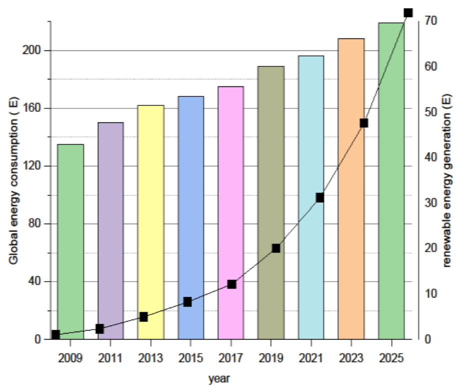

Fig 1. World Electrical Energy Consumption and Growth of RE trends, 2010 - 2022

The continued rise in global average temperatures and the increased volatility of extreme weather events are other driving forces behind renewable energy expansion, Fig 1,[4]. The South African scenario is depicted in the bar graph of Fig 3, [5]. An increase in electrical energy consumption and renewable energy production across various provinces is evident. The blue bars indicate the energy consumption for each province, revealing that Gauteng has the highest consumption, followed by KwaZulu-Natal and the Western Cape. The green bars show renewable energy generation, with the Northern Cape at the forefront, showcasing its significant renewable energy initiatives. This chart underscores the regional differences in energy use and the diverse levels of renewable energy generation among South Africa's provinces.

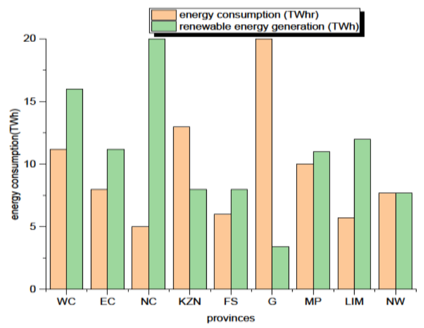

Fig 2. South Africa Energy Consumption and Renewable Energy Generation by province

Asia, Fig 3 is a leading region in renewable energy generation, of which China and India are the driving engines. Europe and North America have substantial renewable energy capacities. The other regions show growing but relatively smaller capacities, reflecting their developing renewable energy infrastructure. Future electricity markets are anticipated to be more flexible, deeply integrated with intermittent renewable energy production, and reliant on Information and Communication Technology (ICT) for ensuring system reliability and efficient management. SGs emerging from this integration, facilitate bi-directional communication among distribution system operators, consumers/prosumers, and decentralized generators. The deployment of intelligent components, particularly Smart Meters, enables demand-side management strategies to control consumption, thus averting the need for costly infrastructure expansion, [1].

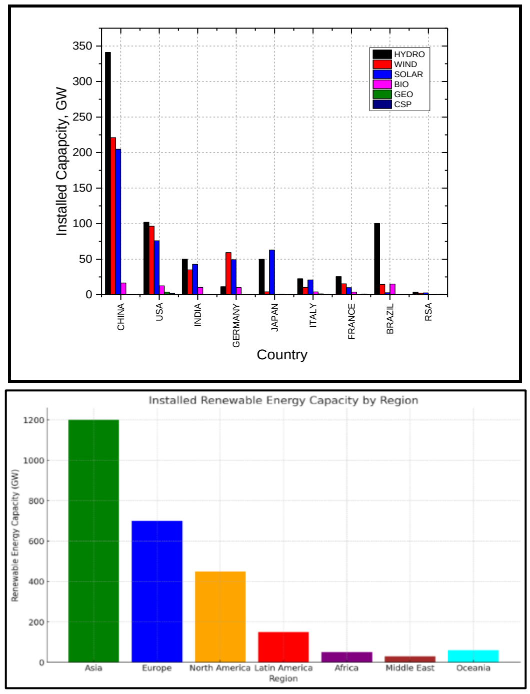

Fig 3. Installed renewable energy capacity by region/country, measured in gigawatts

In South Africa, the predominant utility is Eskom and coal still accounts for +80% of the generation mix[6]. Electrical energy consumption is dominated by three sectors: commercial, including residential & public service, and industry, for which the share of consumption is in the ranges of 15-31, 20-27, and 64%, respectively. The National Development Plan 2030 envisages decommissioning 35 GW (of 42 GW currently operating) of thermal power capacity and supplying at least 20 GW of the additional 29 GW of electricity needed by 2030 from renewables and gas sources. This article looks at the critical role demand-side management will play in the imperative to balance supply and demand in the emerging grid with high penetration of renewables. Optimal techniques to schedule load have been applied to reduce PAR and overall energy consumption costs. Around the world, buildings generally consume approximately 40% of electricity, with the residential sector alone accounting for 25-30%. The fact that domestic loads have greater flexibility in terms of shifting means they have more scope for DSM implementation. Prosumers and independent power producers are actively seeking technology solutions to revolutionize power generation, consumption, marketing, and business models in what is now conceptualized as the Smart Grids (SG, Grid 2.0).

B. Overview of Demand Side Management (DSM).

Electricity supply and demand must consistently balance hence the need for predictive control. Smart Meters offer detailed data on individual entities' electricity consumption. However, demand curves at aggregation points differ significantly from individual metering points. For instance, Fig 4, is a typical load profile at a substation serving a commercial block that illustrates peak demand during business hours, followed by a decline, varying throughout the week and year due to seasonal commercial activity and fluctuating occupancy patterns. The objective of Demand-Side Management (DSM) is to flatten the demand curve by reducing high peaks, extending energy conservation to off-peak hours, and filling valleys. Thus, DSM optimizes energy consumption and mitigates the need for peak capacity. This is often implemented through consumer tariffs that incentivize load shifting to off-peak hours. M.U Saleem and M.R Usman[7] extensive outline of design, deployment, implementation

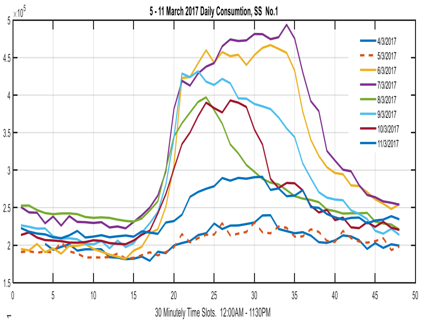

Fig 4. Daily energy consumption for Compus Unit at various times

DSM programs benefit consumers and utilities alike[8]. Consumers reduce electricity bills through DSM-compatible appliances, and utilities manage growing demand cost-effectively. These strategies also mitigate grid stress, reducing the risk of failures and lowering carbon footprints, aligning with environmental goals and regulatory pressures for cleaner energy. Despite challenges in electricity pricing dynamics, market-based pricing and demand response programs incentivize efficient consumption, reducing the need for costly capacity upgrades while enhancing network reliability and reducing outage risks for all stakeholders.

C. Consumer Engagement

Successful implementation and widespread use of DSM techniques rely on a fully informed customer base. However, encouraging active consumer participation in DSM programs remains a challenge. Many consumers are unaware of the benefits or lack the motivation to modify their behaviour. Engaging consumers in DSM adoption requires a comprehensive approach integrating education, incentives, technology, and community engagement. Educational campaigns, personalized energy usage reports, and local workshops are crucial in raising awareness about the benefits and practices. Financial incentives, such as rebates, discounts, and loyalty programs motivate consumers to participate actively in DSM initiatives. Implementing time-of-use pricing further encourages consumers to shift their energy usage to off-peak times, optimizing grid efficiency.

Technological tools like smart meters, energy management apps, and home automation systems empower consumers by providing real-time data and control over their energy consumption. Community engagement through local workshops and peer programs fosters a supportive network where participants can share experiences and learn from each other. Utilizing behavioural insights, such as nudges and immediate feedback mechanisms, can significantly influence consumer behaviour toward more efficient energy use.

Active Power P (kW)								
Name	AVG	MIN	MIN date	MIN time	MAX	MAX date	MAX time	Units
P1 (W) (10 min)	26.168	11.553	4/10/2024	5:10:00.000 AM	98.238	4/24/2024	12:40:00.000 PM	kW
P1+ (W Load) (10 min)	26.168	11.553	4/10/2024	5:10:00.000 AM	98.238	4/24/2024	12:40:00.000 PM	kW
P1- (W Source) (10 min)	---	NA	5/2/2024	11:10:00.000 AM	NA	5/2/2024	11:10:00.000 AM	W
P2 (W) (10 min)	25.924	10.472	4/28/2024	2:40:00.000 AM	92.818	4/24/2024	12:40:00.000 PM	kW

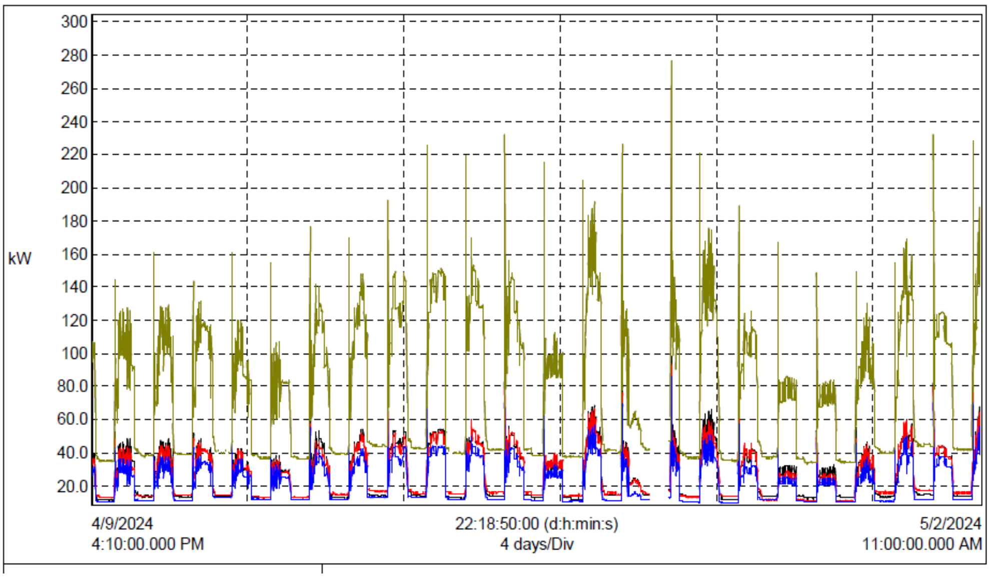

Fig 5. Typical load variation in a commercial building showing daily cyclic load peaking

Supportive policies and regulations, including subsidies for energy-efficient appliances and tax incentives for DSM investments, create an enabling environment for DSM adoption. Clear and transparent communication about DSM programs, benefits, and potential drawbacks builds consumer trust. Partnerships with utility companies and non-profit organizations extend the reach and effectiveness of DSM initiatives. Offering customized DSM solutions tailored to individual household needs, along with robust customer support, ensures that consumers can easily implement and benefit from DSM measures. Continuous evaluation and feedback mechanisms help refine and improve DSM programs, ensuring they remain relevant and effective. This comprehensive approach enhances consumer engagement and contributes to sustainable energy consumption and grid stability. Engaging consumers in demand-side management (DSM) adoption is essential for optimizing energy consumption and enhancing grid stability. Successful engagement strategies typically involve education, incentives, technology, and community involvement.

Fig 5 is kW energy consumption data obtained in real-time in a commercial office building. In each 4 days, consumption can vary by 150kW during active business hours. Consequently, the building power factor drops when wattage usage increases due to several factors. Increased use of inductive loads like motors, HVAC systems, and fluorescent lighting raises the demand for reactive power, thereby lowering the power factor. Additionally, non-linear loads such as computers and electronic devices introduce harmonics that distort the current waveform, further reducing the power factor. Imbalances in load distribution across different phases can create inefficiencies, and inefficient operation of equipment under partial loads can also contribute to a lower power factor. Wider consumer awareness of such adverse effects is needed to achieve more engaged adoption of DSM.

D. DSM Enabling Technologies

The domestic sector is particularly suitable for Demand-Side Management (DSM)[9]. Usman Zafar's

There isn't enough information provided to check for errors. Please provide the specific context or statement that needs to be checked.

et. al. [10] examined home energy management systems (HEMS) within the context of smart grids. Smart homes are key to smart grids, with HEMS optimizing energy usage and incorporating renewable sources. These systems consider factors like energy prices, weather, and load profiles to boost efficiency. Challenges include the integration of power converters and energy storage. Communication networks such as HANs, NANs, and WANs are vital for smart grid functions. Energy storage systems and hybrid renewables are crucial for maintaining power stability in smart homes, while power electronics manage solar and wind energy systems. Smart grids use HEMS to enhance energy savings and efficiency. The architecture of HEMS heavily relies on cloud computing, IoT devices, and smart meters. Companies like Schneider Electric and GE are at the forefront of developing HEMS products. DSM strategies involve price-based or incentive-based demand response programs. Load scheduling employs optimization methods and machine learning. HEMS have advanced to distributed architectures running on standard operating systems, ensuring robustness. The integration of cloud computing, IoT, and Edge computing improves data handling and processing. Optimization techniques such as game theory and machine learning are essential for configuring demand-response in HEMS.

E. Policy Framework

The state of the art in Demand-Side Management (DSM) as it relates to policy and regulatory influences highlights a comprehensive shift towards sustainable energy practices and enhanced grid management. Policymakers are increasingly integrating frameworks that not only incentivize energy conservation but also support the adoption of advanced technologies such as smart grids and energy storage systems. These frameworks are designed to facilitate the integration of renewable energy sources like solar and wind, thereby reducing dependency on fossil fuels and lowering carbon emissions. Regulatory bodies are promoting dynamic pricing models, including time-of-use tariffs and real-time pricing, which encourage consumers to adjust their energy usage based on grid demands and pricing signals. This shift is aimed at flattening peak demand curves, reducing strain on the grid, and promoting more efficient energy use.

Additionally, there is a concerted effort among regulators to create a harmonized policy environment that supports the widespread adoption of DSM technologies. This includes refining demand response programs that offer incentives for reducing consumption during peak periods and implementing stringent energy efficiency standards for appliances and buildings. Policies are increasingly focusing on fostering consumer engagement and investment in DSM, recognizing the role of end-users in achieving energy sustainability. Cross-jurisdictional collaboration is also a key aspect, with efforts to standardize regulations and share best practices to ensure coherent DSM implementation. These policy and regulatory measures collectively aim to enhance grid reliability, promote energy efficiency, and support the transition to a more sustainable and resilient energy system. The report by Stephane de la Rue du Can and Theo Covary[11], found, "Energy Efficiency DSM as an energy resource is underutilized in South Africa and has the potential to meet multiple short- and long-term national objectives." And calls for evolution of supporting regulatory framework.

F. Road map to successful implementation of DSM

Implementing a successful Demand-Side Management (DSM) program for electrical energy consumption involves a structured and comprehensive roadmap. Here is a step-by-step guide.

1. Assessment and Planning

- Energy Audit: Conduct thorough energy audits to understand current energy consumption patterns and identify potential areas for improvement.
- Goal Setting: Define clear, measurable goals for energy savings and peak demand reduction.
- Stakeholder Engagement: Involve all relevant stakeholders, including utility companies, policymakers, business owners, and consumers, to ensure widespread support and collaboration.

2. Policy and Regulatory Framework

- Supportive Policies: Develop and implement policies that incentivize energy efficiency and DSM programs, such as tax credits, subsidies, or grants.
- Regulatory Measures: Introduce regulations that promote the adoption of energy-efficient technologies and practices, including mandatory

energy efficiency standards and time-of-use tariffs.

3. Technological Integration

- Smart Meters and IoT Devices: Deploy smart meters and IoT devices to monitor and manage energy consumption in real-time.
- Home Energy Management Systems (HEMS): Encourage the use of HEMS to optimize energy use in residential buildings.
- Building Management Systems (BMS): Implement advanced BMS in commercial and industrial buildings to enhance energy efficiency.

4. Consumer Engagement and Education

- Awareness Campaigns: Run educational campaigns to inform consumers about the benefits of DSM and how they can participate.
- Behavioral Programs: Introduce programs that encourage energy-saving behaviors, such as demand response programs and real-time feedback on energy usage.
- Incentives: Offer incentives for consumers who participate in DSM programs, such as rebates for energy-efficient appliances or lower rates for off-peak usage.

5. Financial Mechanisms

- Funding and Investments: Secure funding from government grants, private investments, or public-private partnerships to support DSM initiatives.
- Cost-Benefit Analysis: Perform cost-benefit analyses to ensure that DSM programs are financially viable and offer a good return on investment.

6. Implementation and Monitoring

- Pilot Programs: Start with pilot programs to test DSM strategies and technologies on a small scale before wider deployment.
- Data Analytics: Use data analytics to monitor the performance of DSM programs and make data-driven decisions.
- Continuous Improvement: Regularly review and refine DSM strategies based on performance data and feedback from stakeholders.

7. Evaluation and Reporting

- Performance Metrics: Establish key performance indicators (KPIs) to measure the success of DSM programs.
- Regular Reporting: Provide regular reports to stakeholders on the progress and impact of DSM initiatives.
- Adaptation and Scaling: Adapt strategies based on evaluation results and scale successful programs to cover larger areas or more consumers.

By following this roadmap, utility companies, governments, and businesses can effectively implement DSM programs that reduce energy consumption, lower costs, and enhance grid reliability.

F. Conclusion

The importance of "Powering Tomorrow: Exploring Evolving Trends in Demand-Side Management (DSM)" is highlighted in shaping a sustainable energy future. With the increasing global energy needs, DSM tactics present a proactive method to improve energy utilization, bolster grid dependability, and incorporate renewable energy resources. Advancements in technology, including smart meters, IoT devices, and home energy management systems, are transforming the monitoring and management of energy. Policy and regulatory structures are adapting to facilitate these technological developments, encouraging energy efficiency and consumer involvement. Additionally, the increasing focus on consumer engagement and education plays a crucial role in accomplishing the objectives of Demand-Side Management (DSM). By leveraging financial mechanisms and continuous improvement processes, DSM initiatives can be both economically viable and environmentally beneficial. As we move forward, the successful implementation of DSM will be essential in meeting the challenges of energy sustainability, reducing carbon footprints, and ensuring a resilient and efficient energy system for future generations.

References

[1] Tosin Michael Olatunde, Azubuike Chukwudi Okwandu, Dorcas Oluwajuwonlo Akande, and Zamathula Queen Sikhakhane, 'the Impact of Smart Grids on Energy Efficiency: a Comprehensive Review', Eng. Sci. Technol. J., vol. 5, no. 4, pp. 1257–1269, 2024, doi:

10.51594/estj.v5i4.1016.

[2] STATISTA RESEARCH DEPARTMENT, ‘Distribution of electricity generation in Denmark in 2023, by source’, Breakdown of electricity generation in Denmark in 2023, by source, 2024. https://www.statista.com/statistics/1235360/denmark-distribution-of-electricity-production-by-source/

[3] Q. Hassan et al., ‘Technology in Society Mapping Europe renewable energy landscape : Insights into solar , wind , hydro , and green hydrogen production’, Technol. Soc., vol. 77, no. September 2023, p. 102535, 2024, doi: 10.1016/j.techsoc.2024.102535.

[4] International Energy Agency - IEA, ‘Electricity 2024 Analysis and forecast to 2026.’, Int. Energy Agency, pp. 1–170, 2023, [Online]. Available: https://www.iea.org/news/global-coal-demand-expected-to-decline-in-coming-years

[5] O. M. Akinbami, S. R. Oke, and M. O. Bodunrin, ‘The state of renewable energy development in South Africa: An overview’, Alexandria Eng. J., vol. 60, no. 6, pp. 5077–5093, 2021, doi: 10.1016/j.aej.2021.03.065.

[6] B. P. Jele, ‘An analysis of the effect of the intermittent supply of electricity to consumers in the North West Province, South Africa BP Jele’, no. July, 2023.

[7] M. U. Saleem, M. R. Usman, M. A. Usman, and C. Politis, ‘Design, Deployment and Performance Evaluation of an IoT Based Smart Energy Management System for Demand Side Management in Smart Grid’, IEEE Access, vol. 10, pp. 15261–15278, 2022, doi: 10.1109/ACCESS.2022.3147484.

[8] C. Hecht, D. Sprake, Y. Vagapov, and A. Anuchin, ‘Domestic demand-side management: analysis of microgrid with renewable energy sources using historical load data’, Electr. Eng., vol. 103, no. 3, pp. 1791–1806, 2021, doi: 10.1007/s00202-020-01197-y.

[9] S. Balavignesh, C. Kumar, R. Sripriya, and T. Senjyu, ‘An enhanced coati optimization algorithm for optimizing energy management in smart grids for home appliances’, Energy Reports, vol. 11, no. March, pp. 3695–3720, 2024, doi: 10.1016/j.egyr.2024.03.031.

[10] U. Zafar, S. Bayhan, and A. Sanfilippo, ‘Home Energy Management System Concepts, Configurations, and Technologies for the Smart Grid’, IEEE Access, vol. 8, pp. 119271–119286, 2020, doi: 10.1109/ACCESS.2020.3005244.

[11] S. de la Rue du Can and T. Covary, ‘SOUTH AFRICA: FRAMEWORK FOR ENERGY EFFICIENCY DEMAND SIDE MANAGEMENT’, 2023. [Online]. Available: https://escholarship.org/uc/item/6s9464gm