Asian Journal of Water, Environment and Pollution, Vol. 19, No. 6 (2022), pp. 93-102.
DOI 10.3233/AJW220093

A Bibliographic Analysis of Adaptive Techniques for the Development of Environment-Friendly Renewable Energy Systems

Shashi Gandhar*, Jyoti Ohri[1] and Mukhtiar Singh[2]
Department of Electrical and Electronics Engineering, BVCOE, New Delhi, India
[1]Department of Electrical Engineering, NIT, Kurukshetra, India
[2]Department of Electrical Engineering, DTU, New Delhi, India
✉ shashi.abhi@gmail.com

Received January 22, 2022; revised and accepted March 22, 2022

Abstract: Renewable Energy Sources (RES) have always been seen as a sustainable and environment-friendly solution to the energy needs of the globe. It is a club of many sources that have been explored widely in the last five decades, and many ways have been designed to harness energy from these sources. But unavailability at all times and fluctuations affect the power quality and reliability of these units. Many adaptive techniques have been designed to maintain these parameters of energy systems. The development is still going on and will go on to find more efficient techniques to extract reliable and quality power. This study presents a bibliographic view of the research in this area for different adaptive techniques. This study also presented an ongoing trend and the future possibilities and past successes that have been achieved in this arena. In the paper, many papers have been reviewed on the recent development in adaptive techniques for power systems in the last five decades. IEEE, the biggest source platform for researchers and scientists, is considered for a survey and statistical analysis of recent developments. Based on a survey and detailed study, graphical analysis is designed to give a very accomplished perspective of adaptive techniques in energy systems for the researchers. The present study suggested many measures and techniques which can contribute to establishing renewable energy systems, thus, decreasing pollution and providing a clean, green and sustainable environment. This study presents a Hybrid energy system with hybrid adaptive techniques as a key solution to overcome the problem of pollution using RES as much as possible and to satisfy the energy demand also. This study can be a major reference point for researchers and power engineers for providing an environment-friendly and sustainable RES-based energy solutions.

Key words: RES, Neural, fuzzy, ANN, GA, PSO.

Introduction

For more than 100 years ago, renewable energy resources have been explored for producing electric energy. But in the last three decades, these are becoming the most sought-after areas not only for energy suppliers but also for research and also gradually capturing the market of energy providers around the world. India has a rich source of energy like solar, hydro, wind, etc. This is primarily because of two reasons: one is the exponential growth in the energy demand and the second is the burning of fossil fuels. But these renewable resources of energy are clean and environmentally friendly and also can provide sustainability. Hence development and

*Corresponding Author

commercialization are the need of the hour to have a sustainable future.

Although these sources are not exhaustible, they exhibit many contingencies such as all-time availability and fluctuations. Tharani et al. (2020) in their study have discussed the availability of solar energy and its dependency on distinct day timings and weather conditions. Similarly, variations in wind speed and patterns are the decisive factors for wind energy selection. A very large sum for installation and engineering is required for the commissioning of this type of energy generating unit. But due to the current developments in the field of adaptive and intelligent techniques in power systems, these factors can be accounted for, and adaptive technique-based FACTS controllers can be designed to extract the reliability and quality of power. Gandhar et al. (2012) emphasised the effectiveness and importance of FACTS controllers in power systems.

Table 1: A summary of IEEE publications in 1991-2000

Sr No.	*Author & Year*	*Technique/Approaches*	*Key findings*
1	Park et al. (1991)	ATNN(Adaptively Trained Neural Network)	The ATNN is based totally on nonlinear programming strategies that were developed for estimating electric load.
2	Chen et al. (1992)	Systematic optimization with suitable weighting matrix	Under the parameters of pre-specified closed-loop dominant eigenvalue places and comments advantage limit barriers, a method for designing linear most appropriate strength system stabilisers.
3	Kamas and Sanders (1993)	Lyapunov function based an adaptive estimation algorithm	For estimating unknown circuit parameters as well as unmeasured circuit variables, the Lyapunov feature is based on an adaptive estimation system. Averaging and singular perturbation evaluation are used to decide the mixed parameter and nation estimate scheme's exponential stability.
4	Birch et al. (1994)	Neural networks (NN)	In parallel with a complete load frequency, an adaptive manipulation technique, a NN is used.
5	Mandal and Sinha (1995)	Multi-layered feedforward (MLFF) neural network	As a decentralized load control technology, the MLFF neural community is applied to estimate bus-load calls at the substation stage.
6	Young-Moon et al. (1996)	Adaptive fuzzy logic	To boom the damping of low frequency oscillations in power systems, an adaptive fuzzy good judgment controller became advanced. System with two machines and 5 buses.
7	Zhao et al. (1997)	Genetic algorithm (GA) technique	For a nuclear steam producing system, a hybrid multi-enter and multi-out (MIMO) manage device which includes feedforward manage (FFC) and feedback manage (PEC) is proposed for a wide range of situations utilizing the genetic set of rules (GA) approach.
8	Zhishan et al. (1998)	Adaptive robust fuzzy	The preliminary step of this research is to develop an adaptive sturdy fuzzy controller to enhance temporary balance for fashionable nonlinear systems with uncertainties that satisfy the matching constraints.
9	Ibrahim et al. (1999)	Fuzzy-adaptive	Individual shrewd paradigms and the layout of prototype adaptive fuzzy structures for electricity first-rate analysis are offered.
10	Song et al. (2000)	Nonlinear and adaptive control theory.	Increasing the performance and reliability of wind power conversion structures through the use of nonlinear and adaptive management strategies.

The world leaders in the generation of electricity from renewable are China with 895 GW, the USA with 292 GW and Brazil with 150 GW. India ranks in the fourth position in harnessing energy from RES. India is working very aggressively in the development of renewable energy units. Therefore, these techniques are becoming very popular research areas for scientists and researchers working on such RES-based projects.

In this study, a very extensive review has been presented of the recent developments for adaptive and intelligent approaches in power systems for designing a robust and efficient control system for RES-based Units. World's biggest research database platform IEEE has been analyzed for the last 5 decades (1970-2020) for the research growth of different adaptive techniques such as neural, fuzzy, GA, etc., and also for popular renewable energies like wind, solar, tidal, etc. A scatter chart analysis is also presented with these data from 1970 to 2020.

It became the need of the hour to find and understand the trend of development in renewables and their control systems to match up the demands and the development done in the last five decades.

Literature Review

This section summarises some important publications (mentioned in Tables 1-3) from the world's biggest research database IEEE from 1990 to 2020. The publications are arranged in chronological order of their publishing in various journals in the field of adaptive techniques used in power systems.

The presented columns are categorised as a year of publication, an adaptive technique used and the key findings in their paper:

Figure 1 directly depicted the need for RES systems that can contribute efficiently with respect to air pollution and clean environment. These RES can significantly reduce air pollution, and CO_2 emissions and lower ill-health effects. On the other hand, conventional thermal power systems can be vulnerable to environmental conditions like climate change. These RES systems also decrease the water scarcity problem as solar, wind and some other RES technologies using dry cooling can fulfill the load demand without water resources. In Figure 1 two sections are presented one is GHG emissions for conventional energy sources and another one is for renewables. The estimated GHG emissions in the case of renewables are very less almost negligible in comparison to traditional sources of energy generation. The Renewables are clearly contributing to the making of the environment clean and pollution free. These are also helping to provide energy-sustainable solutions.

Inferences of Analysis of Publications

In this section, a statistical evaluation of published articles in journal is presented which is an effective

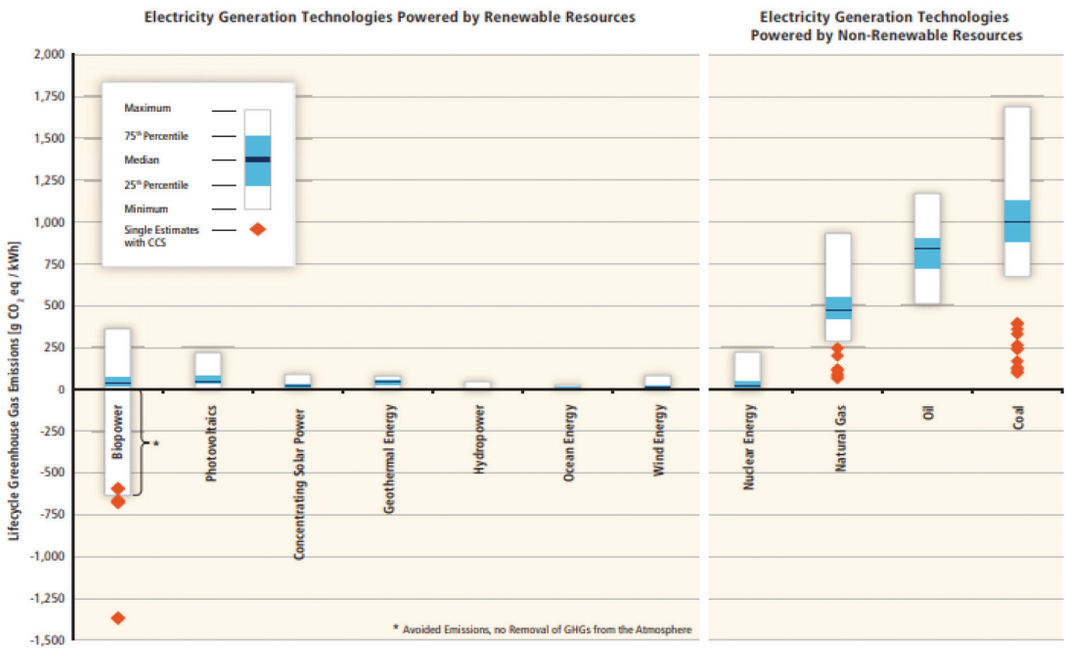

Figure 1: Estimates of life-cycle GHG emissions (g CO_2 eq/kWh) for broad categories of electricity generation technologies (SRREN Summary for Policymakers, 2021).

way to guide future researchers working in the area of renewable technologies. A comprehensive analysis of research papers from the IEEE database on RES and adaptive approaches for controlling different parameters of power systems from 1970 to 2020 is presented in this section. The scatter charts are also presented for analysis purpose. These charts are designed with different parameters from different types of sources from IEEE. These sources are journals, conferences, books, magazines, etc. Figure 2 presented the recent developments of different renewables from 1970 to

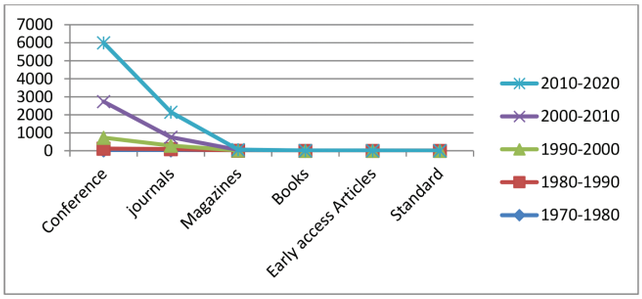

Figure 2: The no. of publications on adaptive techniques in energy sources (1970-2020).

Table 2: A summary of IEEE publications in 2001-2010

Sr No.	*Author & Year*	*Technique/Approaches*	*Key findings*
1	Binato et al. (2001)	GRASP(Greedy Randomized Adaptive Search Procedure)	GRASP can be used to conquer the problem of transmission community boom. This is a professional iterative sampling technique with every iteration.
2	Lin et al.(2002)	Fuzzy-adaptive Neural Network	For superior spindle motor applications, AFNC is proposed to govern the rotor velocity of an induction spindle motor making use of synchronous pulse-width modulation (PWM).
3	Venayagamoorthy et al. (2003)	Neural using Dual heuristic programming (DHP) approach	In a multi-machine strength device, a neural controller primarily based on twin heuristic programming (DHP) is devised for the excitation manipulation of turbo-generators.
4	Terzija et al.(2004)	Linear Least Error Squares Estimation Technique	The car reclosure algorithm, which makes use of a linear least error squares estimate method for medium-voltage overhead traces, is explained.
5	Awadallah et al.(2005)	Neuro-fuzzy	A neuro-fuzzy-primarily based technique for the automation of stator-winding inter-turn brief circuit detection and placed in CSI-fed brushless dc motors.
6	Ibrahim and Morcos (2006)	Adaptive fuzzy	A sensible adaptive fuzzy machine with self-getting-to-know capabilities that could display electrical equipment or systems and self-examine the activities that make contributions to the monitored system's failure.
7	Qiao and Harley (2007)	RBFNN (Radial Basis Function Neural Networks)	To improve the damping performance of an electricity community, an indirect adaptive external neuro-controller (INDAEC) based totally on RBFNN is proposed. The SCRC or the power network do no longer want to be mathematically modeled for this nonlinear INDAEC.
8	Pindoriya et al. (2008)	An AWNN(Adaptive Wavelet Neural Network)	In the energy markets, an adaptive wavelet neural community (AWNN) for short-time-period price forecasting (STPF). The activation function for feed-forward neural network (FFNN) hidden-layer neurons is a typically used Mexican hat wavelet.
9	Pan and Jain (2009)	Digital AVP(Adaptive Voltage Positioning) technique	Fixed-frequency top modern-day mode manipulate is used by an AVP with a quick brief response for voltage regulators.
10	Vlachogiannis et al. (2010)	PSO (Particle Swarm Optimisation)	The surest financial load dispatch hassle in electricity structures has solved the use of an aggregation-based PSO algorithm.

Table 3: A summary of IEEE publications in 2011-2020

Sr No.	*Author & Year*	*Technique/Approaches*	*Key findings*
1	Kusljevic and Poljak (2011)	Weighted-least-square (WLS)	The weighted-least-square method-based algorithm. Is designed to minimise the noises and eliminate harmonics.
2	Meza et al. (2012)	Control scheme based on Lyapunov	A method for single-segment single-degree grid-related photovoltaic important inverters with uncertainty based totally on solar irradiance is defined.
3	Wang and Truong (2013)	ANFIS(Adaptive-Network-Based Fuzzy Inference System)	Under varied operating situations, an SVC using ANFIS contributes suitable damping qualities to the prominent modes of the examined synchronous generators.
4	Rajendran and Jena (2014)	Adaptive fuzzy integral sliding mode control (AFISMC)	An AFISM-based VSWT controller for distinct disturbances is designed. A comparative study with sliding mode control and integral sliding mode control methods.
5	Chikh and Chandra (2015)	Geometric programming technique/ neural network	A computing system that adjusts its power calls. Under variable solar power supply, the geometric programming technique is used to maximise energy utilisation.
6	Kumar et al. (2016)	Adaptive sliding-mode (SM) technique	This work offers a unique resilient and adaptive sliding-mode (SM) control for a grid-connected photovoltaic (PV) system based on a cascaded two-level inverter (CTLI) to deliver active and reactive power with varying solar irradiation.
7	Song et al. (2017)	Neural network (NN)	Neural Network based analytical model for the analysis of deflections in the power profiles.
8	Singh et al. (2018)	Load-oriented control parameter optimisation technique	To increase low-frequency oscillation damping (LFOD) and overall complex power system stability, this research provides a load-oriented control parameter optimisation technique for static synchronous compensator (STATCOM). The designed supplemental damping controller of STATCOM uses frequency variations of interest generators as input signals.
9	Kermadi et al. (2019)	Particle swarm optimisation (PSO)	With real partial shade and load conditions, an adaptive PSO based algorithm is used for maximum power point tracking (MPPT).
10	Fekry et al. (2020)	Adaptive Neuro fuzzy inference system (ANFIS)	A PMS based on ANFIS for an hybrid microgrid system with wind and PV energy sources.

Table 4: Developments of adaptive techniques in power systems (1970-2020)

Sources	*1970-1980*	*1980-1990*	*1990-2000*	*2000-2010*	*2010-2020*
Conference	30	93	607	2005	3266
Journals	32	65	192	468	1392
Magazines	0	7	13	34	18
Books	0	0	0	2	15
Early access Articles	0	0	0	0	12
Standard	0	0	0	3	2

2020. The most popular RES resources, such as solar, wind, hydro, etc .are considered for the presentation.

In the area of solar systems and PV cells, there was more focus on maximum power point tracking (MPPT) with different models to further increase the efficiency of photovoltaic modules and the modules were combined with sensors, IC circuits and wireless connectivity to perfect its working under varying solar conditions. Hasarmani et al. (2020) have presented an optimised hybrid design of PV and diesel for controlling the disturbances introduced by non-conventional sources.

Table 5: Developments of different renewable source based systems (1970-2020)

Sources	*Solar*	*Wind*	*Hydro*	*Geo*	*Biomass*	*Tidal*
Conferences	15019	26976	2514	498	965	426
Journals	2067	5522	586	25	42	77
Magazines	115	463	81	13	29	11
Standards	41	55	17	0	0	0
Books	30	113	11	29	14	2

Tables 3 and 5 exhibit the analysis and pairing of solar with diverse types of renewable sources like geothermal, hydro. wind etc. These tables also present the simulated analysis of these combinations in real-life situations. The biofuel was considered an auxiliary power unit for vehicles, and its efficiency was also calculated. In hybrid energy, solar and wind generators are combined to create a renewable hybrid energy system. Figure 3 (is designed based on the data mentioned in Table 5) shows the developments in the areas of adaptive and intelligent techniques. Here most popular techniques are considered for analysis. Figure 4 presents the scatter chart designed for neural, fuzzy, GA, PSO, etc techniques and their progress in the last five decades i.e., 1970-2020. These charts are prepared on the basis of data specified in Table 6. It is clearly

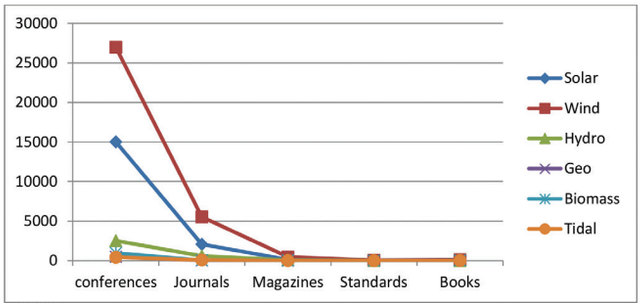

Figure 3: The no. of publications on different renewable energy sources (1970-2020).

shown that in the first three decades 1970-2000 the neural and fuzzy techniques were immensely popular among all but in the last two decades, GA and PSO become the most prominent technique for designing the control system for power systems, A notable mention is, GA is used to optimize the glazed efficiency of single PV cell by Singh et al. (2014). The integration of these approaches is clearly improving the efficiency of the power networks by increasing the reliability and quality of electric power.

Table 6: Developments of different adaptive/ optimisation techniques (1970-2020)

Sources	*FUZZY*	*ANN*	*ANFIS*	*GA*	*PSO*
Conferences	2373	12551	1327	15708	14302
Journals	428	1617	145	2103	1666
Magazines	43	79	3	68	39
Standards	5	34	2	17	12
Books	1	7	1	9	7

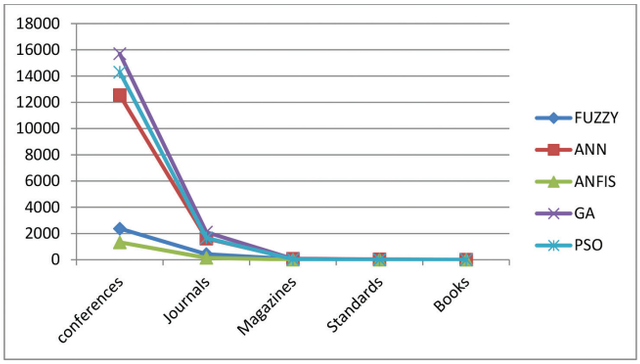

Figure 4: The publications on the development of adaptive techniques (1970- 2020).

These key findings show notable progress with future commitments in the field of renewable energy and adaptive techniques for better control of various parameters of power systems. The advent of advanced simulation and energy management software like Simulink, ETAP, etc. in the past few decades helped a lot in the easy implementation of ideas and summarise analysis. All these analysis presentations can make an impact on the renewable application and its control with the help of improved hybrid adaptive techniques.

Simulation Results

A microgrid framework proposed by Bansal (2006), is examined for simulation work, with a synchronous generator as a diesel system, Induction Generator as a wind system. Here, in this study, a fuzzy tuned FACTS

controller 'UPQC' is implemented with a microgrid system for managing the disturbances carried out by the renewable energy sources. The simulation is carried out to test micro-grid framework in MATLAB/ SIM POWER SYSTEM software. Bansal (2009) has considered stochastic disturbances with fixed step size. Similarly this paper presents the analysis of test system under random disturbances.

In this section, the different membership functions of inputs responsible for the change in voltage of the proposed microgrid with fuzzy tuned FACTS controller 'UPQC' are presented. This test system is subjected to practical disturbances in reactive power loading.

The six defined MFs are designed for different gain settings of the controller Kp and Ki and these gain settings are obtained for the output 'change in voltage'.After designing of these MFs the 36 if-then rules are framed in Fuzzy logic. These are shown in Figure 6. Mohanty et al. (2013) have also designed the self tuned fuzzy controller for UPFC, similarly, this controller is designed for UPQC shown in Figure 5. A Fuzzy Inference System (FIS) is designed on the basis of these rules and Figure 7 depicts the surface view of the change in voltage for the obtained values of gain settings of controller. This surface view clearly shows the peaks of the change in voltages for the designed settings of controller.

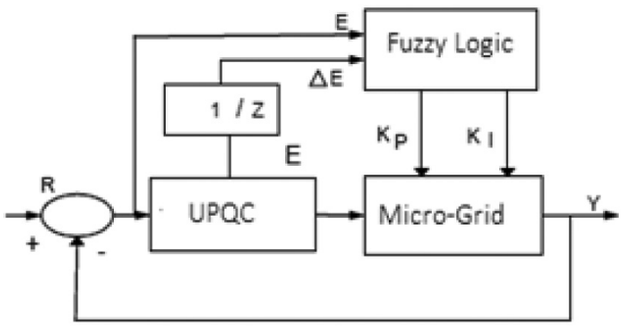

Figure 5: Fuzzy logic controller.

Kp \ Ki	B	VL	L	M	H	VH
B	VL	M	VL	H	VH	H
VL	L	M	VL	H	VH	H
L	B	VL	L	H	B	VL
M	B	M	M	VH	B	VL
H	VL	B	M	H	VH	L
VH	L	M	VL	VH	B	VL

Figure 6: Fuzzy rules.

Table 7: The settling time for transients

Type of system	ΔQ_{IG}	ΔQ_{SG}	ΔQ_{UPG}	ΔV
Untuned	0.015	0.020	0.020	0.015
Fuzzy Tuned System				

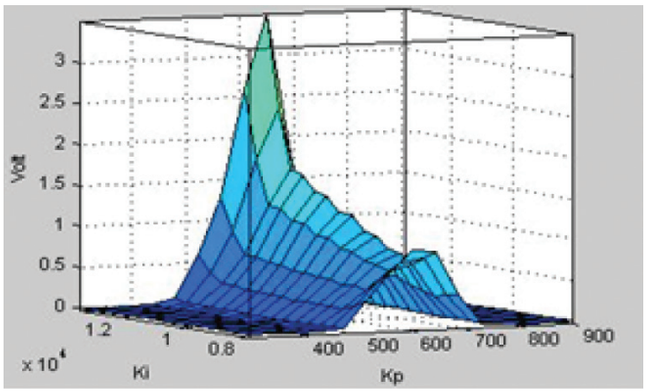

Figure 7: Fuzzy surface view.

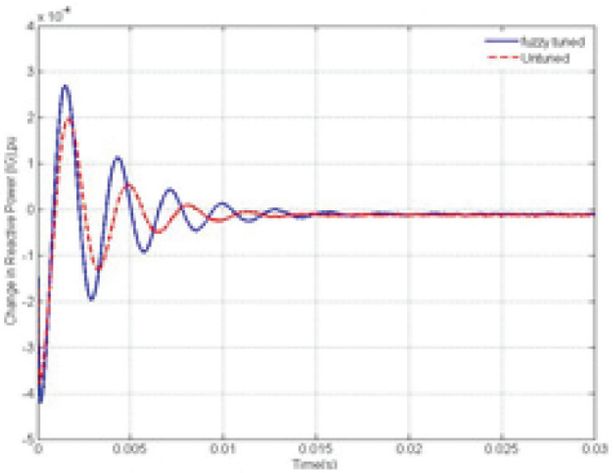

Figure 8: Change in reactive power of SG.

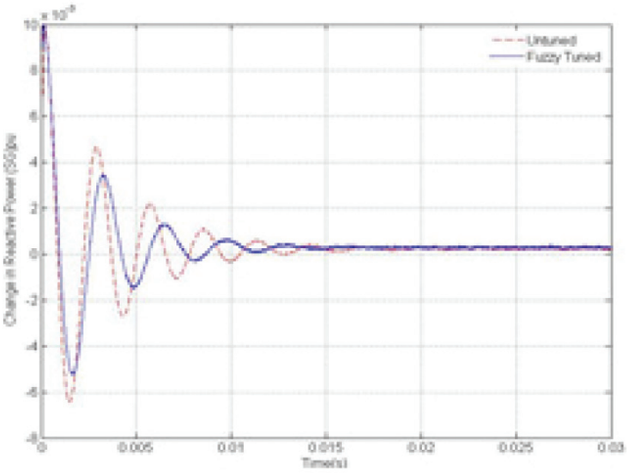

Figure 9: Change in reactive power of IG.

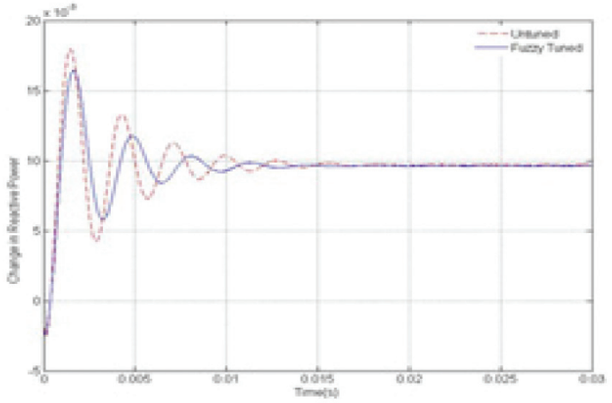

Figure 10: Change in reactive power of UPQC.

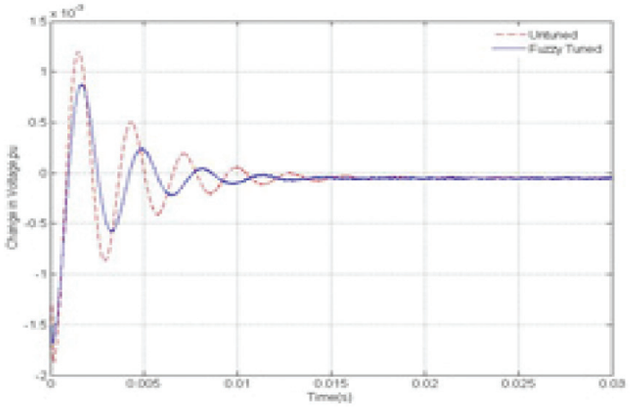

Figure 11: Change in voltage.

The dynamic responses are presented in Figures 8-11 with fuzzy tuned FACTS controller UPQC. These figures show the transient responses for variable reactive power loading. Here all responses are presented in the form of settling periods. The settling time of both types of systems is recorded in Table 7. The presented responses clearly make a statement that the fuzzy tuned system is settling faster than the unturned system. In this manner, these simulation results are also supporting the impact of the adaptive technique on the renewable-based systems.

Recommended Protocol for Future Prospects of Renewables

Based on the study presented, some recommendations can be considered for the future prospects of renewable energy sources. These are suggested based on the associated concerns of most impact:

- Sizing and storage capacity
- Impact of weather
- Advancement in control technology

Government and power sector industries must focus on the potential of RES and some recommendations may be adopted especially in India:

- Awareness about renewables and their environmental benefits must be a key factor for the future growth of RES.
- The government must allocate a separate budget for RES-based energy solutions. India's annual budget for RES is only USD 10.9 billion (INR 75500 crore) which is very less in comparison to USA and China. (National Electricity Plan, 2016).
- There must be industry-academia research bonding, which must support R&D solutions in the area of control of RES-based systems. The prediction and influence of weather conditions on RES can be managed by adaptive techniques. In this regard, hybrid adaptive techniques provide better and more effective solutions.
- The most important finding of the presented study is the hybridisation of renewable systems with conventional power systems which can improve the performance of energy sectors. In this regard, governments and agencies should formulate protocols and policies for hybrid systems.

The protocol used in this analysis shows that the hybridisation of different energy sources and the requirement of adaptive techniques for better control is the need of the hour. Time and money can be saved if the mentioned findings and processes are adopted in the initial phases. This can benefit energy sectors to protect the globe for future generations.

Conclusion

An extensive review on the study and development of RES and adaptive techniques for designing a robust and efficient control system has been presented. It is concluded that a consistent and continuous improvement in the RES-based technologies and the advancement in the integration of adaptive techniques can improve the reliability and quality of electrical energy. The simulation study further endorsed the implementation of adaptive approaches in renewable-based systems. Some of the prominent research consists of PSO with GA integration with wind and photovoltaic cells can be the point of interest for researchers. While in recent times there is research areas focused on hybrid

generation i.e. implementation of multiple renewables to improve the reliability of supply. Similarly, hybrid adaptive techniques i.e. integration of multiple approaches such as neural-fuzzy or GA with PSO can be implemented in hybrid energy systems to give much better results i.e., much improved reliability and control over the fluctuations of renewables. Further research and development in the field of adaptive techniques controlled RES-based units can be a viable solution to the world's energy demand and become a boon to the environment.

References

Awadallah, M.A., Morcos, M.M., Gopalakrishnan, S. and T.W. Nehl (2005). A neuro-fuzzy approach to automatic diagnosis and location of stator inter-turn faults in CSI-fed PM brushless DC motors *IEEE Transactions on Energy Conversion*, **20(2):** 253-259. doi: 10.1109/TEC.2005.847976

Bansal, R.C. (2006). Automatic reactive-power control of isolated wind diesel hybrid power systems. *IEEE Trans. on Industrial Electronics*, **53(4):** 1116-1126.

Bansal, R.C. (2009). ANN based reactive power control of isolated wind diesel micro-hydro hybrid power systems. *International Journal of Modelling, Identification and Control*, **6(3):** 196-204.

Binato, S., de Oliveira, G.C and J.L. de Araujo (2001). A greedy randomized adaptive search procedure for transmission expansion planning. *IEEE Transactions on Power Systems*, **16(2):** 247-253. doi: 10.1109/59.918294

Birch, A.P., Sapeluk, A.T. and C.S. Ozveren (1994). An enhanced neural network load frequency control technique. Paper presented at the 1994 International Conference on Control - Control '94., **1:** 409-415. doi: 10.1049/cp:19940167

Chen, G., Malik, O.P., Qin, Y. and G. Xu (1992). Optimization technique for the design of a linear optimal power system stabilizer, *In:* IEEE Transactions on Energy Conversion, **7(3):** 453-459. doi: 10.1109/60.148566

Chikh, A. and A. Chandra (2015). An optimal maximum power point tracking algorithm for PV systems with climatic parameters estimation. *IEEE Transactions on Sustainable Energy*, **6(2):** 644-652. doi: 10.1109/TSTE.2015.2403845

Edenhofer, Ottmar & Pichs, Ramon & Sokona, Youba & Arvizu, Dan & Bruckner, Thomas & Christensen, John & Devernay, Jean-Michel & Faaij, A.P.C. & Fischedick, Manfred & Goldstein, et al. (2021). SRREN Summary for Policymakers.

Fekry, H.M. Eldesouky, A.A., Kassem, A.M. and A.Y. Abdelaziz (2020). Power management strategy based on adaptive neuro fuzzy inference system for AC microgrid. *In:* IEEE Access, **8:** 192087-192100. doi: 10.1109/ACCESS.2020.3032705

Gandhar, A., Singh, B. and R. Khanna (2012). Impacts of FACTS technology: A state of art review. *International Journal of Innovative Technology and Exploring Engineering (IJITEE)*, **1(4):** 28-31.

Hasarmani, T., Holmukhe, R., Gandhar, A. and S. Bhardwaj (2020). Optimum Sizing and Performance Assessment of Solar PV-DG Hybrid System for Energy Self Sufficiency of Jaggery Making Units. Paper presented at the IEEE Bangalore Humanitarian Technology Conference (B-HTC) 2020, October 08-10, 2020.

Ibrahim, W.R.A. and M.M. Morcos (2006). An adaptive fuzzy self-learning technique for prediction of abnormal operation of electrical systems. *In:* IEEE Transactions on Power Delivery, **21(4):** 1770-1777. doi: 10.1109/TPWRD.2006.881795

Ibrahim, W.R.A., Morcos, M.M. and D.G. Kreiss (1999). An adaptive neuro-fuzzy intelligent tool and expert system for power quality analysis. I. An introduction. Paper presented at the 1999 IEEE Power Engineering Society Summer Meeting. Conference Proceedings (Cat. No.99CH36364), **1:** 493-498. doi: 10.1109/PESS.1999.784400

Kamas, L.A. and S.R. Sanders (1993). Parameter and state estimation in power electronic circuits. *In:* IEEE Transactions on Circuits and Systems I: Fundamental Theory and Applications, **40(12):** 920-928. doi: 10.1109/81.269033

Kermadi, M., Salam, Z., Ahmed, J. and E.M. Berkouk (2019). An effective hybrid maximum power point tracker of photovoltaic arrays for complex partial shading conditions. *IEEE Transactions on Industrial Electronics*, **66(9):** 6990-7000. doi: 10.1109/TIE.2018.2877202

Kumar, N., Saha, T.K. and J. Dey (2016). Sliding-mode control of PWM dual inverter-based grid-connected PV system: Modeling and performance analysis. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, **4(2):** 435-444. doi: 10.1109/JESTPE.2015.2497900

Kusljevic, M.D.K. and P.D. Poljak (2011). Simultaneous reactive-power and frequency estimations using simple recursive WLS algorithm and adaptive filtering. *IEEE Transactions on Instrumentation and Measurement*, **60(12):** 3860-3867. doi: 10.1109/TIM.2011.2144690

Lin, F.-J. and R.-J. Wai (2002). Adaptive fuzzy-neural-network control for induction spindle motor drive. *In:* IEEE Transactions on Energy Conversion, **17(4):** 507-513. doi: 10.1109/TEC.2002.805225

Mandal, J.K. and A.K. Sinha (1995). Artificial neural network based hourly load forecasting for decentralized load management. Paper presented at the Proceedings 1995 International Conference on Energy Management and Power Delivery EMPD '95, **1:** 61-66.

Meza, C., Biel, D., Jeltsema, D. and J.M.A. Scherpen (2012). Lyapunov-based control scheme for single-phase grid-

connected PV central inverters. *IEEE Transactions on Control Systems Technology*, **20(2):** 520-529.

Mohanty, A., Mohanty, S.R., Kishor, N. and P.K. Ray (2013). Adaptive fuzzy tuned PID and UPFC for reactive power compensation in distributed generation system, Paper presented at the Proc. of the Second Intl. Conf. on Advances in Electronics and Electrical Engineering — AEEE. pp. 77-82. doi:10.3850/ 978-981-07-5939-1_24

National Electricity Plan (2016). Generation, Central Electricity Authority (CEA), Volume 1, Ministry of Power, GOI.

Pan, S. and P.K. Jain (2009). A new digital adaptive voltage positioning technique with dynamically varying voltage and current references. *IEEE Transactions on Power Electronics*, **24(11):** 2612-2624.

Park, D.C., El-Sharkawi, M.A. and R.J. Marks (1991). An adaptively trained neural network. *IEEE Transactions on Neural Networks*, **2(3):** 334-345. doi: 10.1109/72.97910

Pindoriya, N.M., Singh, S.N. and S.K. Singh (2008). An adaptive wavelet neural network-based energy price forecasting in electricity markets. *IEEE Transactions on Power Systems*, **23(3):** 1423-1432. doi: 10.1109/TPWRS.2008.922251

Qiao, W. and R.G. Harley (2007). Indirect adaptive external neuro-control for a series capacitive reactance compensator based on a voltage source PWM converter in damping power oscillations. *IEEE Transactions on Industrial Electronics*, **54(1):** 77-85. doi: 10.1109/TIE.2006.888759

Rajendran, S. and D. Jena (2014). Variable speed wind turbine for maximum power capture using adaptive fuzzy integral sliding mode control. *Journal of Modern Power Systems and Clean Energy*, **2(2):** 114-125. doi: 10.1007/s40565-014-0061-3

Singh, B., Kandpal, M. and I. Hussain (2018). Control of grid tied smart PV-DSTATCOM system using an adaptive technique. *In:* IEEE Transactions on Smart Grid, **9(5):** 3986-3993. doi: 10.1109/TSG.2016.2645600

Singh, S., Agrawal, S. and Avasthi (2014). Optimization of Design Parameters of Glazed Hybrid Photovoltaic Thermal Module using Genetic Algorithm. Paper presented at the *2014 Innovative Applications of Computational Intelligence on Power, Energy and Controls with their impact on Humanity (CIPECH)*, pp. 405-410. DOI: 10.13140/2.1.1215.1368

Song, Y.D., Dhinakaran, B. and X. Bao (2000). Control of wind turbines using nonlinear adaptive field excitation algorithms. *In: Proceedings of the 2000 American Control Conference. ACC (IEEE Cat. No.00CH36334)* **3:** 1551-1555. doi: 10.1109/ACC.2000.879461

Tharani, K., Gandhar, A. and A. Gupta (2020). Performance analysis and comparison of batteries using off-grid PV system. *Asian Journal of Water, Environment and Pollution*, **17(02):** 23-28.

Terzija, V.V. and Z.M. Radojevic (2004). Numerical algorithm for adaptive autoreclosure and protection of medium-voltage overhead lines. *In:* IEEE Transactions on Power Delivery. **19(2):** 554-559. doi: 10.1109/TPWRD.2003.823184

Venayagamoorthy, G.K., Harley, R.G. and D.C. Wunsch (2003). Dual heuristic programming excitation neuro control for generators in a multimachine power system. *In:* IEEE Transactions on Industry Applications, **39(2):** 382-394. doi: 10.1109/TIA.2003.809438

Vlachogiannis, J.G. and K.Y. Lee (2010). Closure to discussion on "Economic Load Dispatch—A comparative study on heuristic optimization techniques with an improved coordinated aggregation-based PSO. *IEEE Transactions on Power Systems*, **25(1):** 591-592. doi: 10.1109/TPWRS.2009.2037534

Wang, L. and D. Truong (2013). Stability enhancement of a power system with a PMSG-based and a DFIG-based offshore wind farm using a SVC with an adaptive-network-based fuzzy inference system. *IEEE Transactions on Industrial Electronics*, **60(7):** 2799-2807. doi: 10.1109/TIE.2012.2218557

Young-Moon P., Un-Chul, M. and K.Y. Lee (1996). A power system stabilization with an adaptive fuzzy logic controller. *In:* Proceedings of 35th IEEE Conference on Decision and Control, **2:** 2191-2195.

Zhishan, L., Kaiyan, P. and H. Zhang (1998). Robust adaptive fuzzy excitation control of multi-machine, electric power system. POWERCON '98. 1998 International Conference on Power System Technology. Proceedings (Cat. No.98EX151), **2:** 804-808. doi: 10.1109/ICPST.1998.729196

Zhao, Y., Edwards, R.M. and K.Y. Lee (1997). Hybrid feedforward and feedback controller design for nuclear steam generators over wide range operation using genetic algorithm. *In:* IEEE Transactions on Energy Conversion, **12(1):** 100-105. doi: 10.1109/60.577288