ISSN: 0974-8571 Vol.13 No. 2 December, 2021

International Journal of Computational Intelligence in Control

Switched Capacitor Inverter Topology Photovoltaic Applications

DR.B.MOULI CHANDRA[1] DR B VENKATA PRASANTH[2]
DR. C. RAJSELVAN3, DR. MANJUNATH T.C.
[1]Professor and HoD, Dept of EEE, QIS College of Engineering & Technology, Ongole, AP, India
[2,3,4] Professor Dept of EEE, QIS College of Engineering & Technology, Ongole, AP, India,

ABSTRACT:

This research proposes a novel switching capacitor inverter topology for solar applications. The inverter can convert low voltage direct current (DC) into high voltage DC and then, in a single stage, invert it to the necessary voltage level with excellent quality. Comparing the suggested inverter to the traditional multilevel inverter topology, the proposed inverter features a distinctive extended structure that minimises the number of parts and devices. Additionally, some of the switches in the architecture work at low frequencies, which reduces switching losses and boosts efficiency. By using level-shifting carrier-based Pulse Width Modulation (PWM) technology, which keeps the capacitor voltages balanced, the inverter is switched. The results of a simulation conducted in MATLAB/SIMULINK to validate the suggested topology operation are presented. The proposed inverter is thoroughly compared to other inverters that have been suggested in the literature.

KEY WORDS:

Switched Capacitor, Multilevel inverter, Voltage balancing in capacitors, Level shifted PWM technique.

INTRODUCTION

Multilevel inverters (MLIs) have recently gained popularity among researchers who study topics like renewable energy integration and high power converters, among others. MLIs can produce waveforms that are almost sinusoidal, which helps with the power quality issue. In essence, MLIs convert a number of DC voltage sources into a high-quality AC voltage waveform. Cascaded H bridge inverter topology, diode clamped inverter topology, and capacitor clamped inverter topology are the three general types into which MLIs fall.

The main disadvantage of diode clamped inverter topology is that it shares unequal voltage between series connected capacitors and also it requires many diodes to produce more number of voltage levels at the output. Some of the advanced diode clamped inverter topologies are presented in [1]-[4]. In those topologies, active devices take the place of diodes, but because of the high total conduction voltage at zero vectors, conduction losses are increased. Numerous H bridges are connected in series to form a cascaded MLI. A distinct DC supply is necessary for each H Bridge. When all of the H Bridge's DC sources have the same magnitude, the configuration is said to be symmetrical; however, if the magnitudes of the DC sources differ, the design is said to be asymmetrical. Asymmetrical arrangements can provide more numbers when compared to a symmetrical design, levels at the load When compared to symmetrical configuration, regulating the asymmetrical configuration is significantly more difficult. Additionally, for higher levels in both configurations, there are more DC sources and devices.

Photovoltaic (PV) applications, generally requires a DC-DC boost converter to step up a low DC voltage into a high DC voltage as required by the grid or the standalone load. This high DC voltage is again inverted in to AC voltage using a high quality MLI. Thus it requires two stages of conversion. First stage is to step up the low voltage DC of PV in to high voltage and the second stage is to convert the high DC voltage generated from first stage into AC voltage of high quality. Thus this two stage conversion increases the system complexity and reduces the efficiency of the system. This paper proposes a new extendable capacitor clamped MLI using switched capacitor topology. Further the proposed inverter uses a level shifting carrier based Pulse Width Modulation method to trigger the devices of the inverter. The main advantage of the proposed inverter is that the number of components used is minimized due to its combined structure. Further the proposed inverter can be extended to any required number of levels just by adding four switches and four capacitors. The remaining part of the paper is organized as follows. Topology derivation is derived in section II. In section III PWM topology for capacitor voltage balancing is dealt in detail. Finally, simulation results are detailed in Section III.

PROPOSED TOPOLOGY

The proposed topology is shown in figure 1, which consists of conventional H bridge and a switched capacitor network connected to the front end of the conventional H bridge. The switched capacitor topology (SCT) is proposed in [5]-[8] as shown in figure 1 in dotted structure. The SCT has four capacitors and eight power devices. Switches S_1, S_4, S_{1B}, S_{2A} are named as S_P switches and S_2, S_3, S_{1A}, S_{2B} are named as S_N switches. The operation of the proposed inverter has two states. In state A S_P switches are turned ON and in state B S_N switches are turned ON as shown in figure 2(a) and 2(b) respectively.

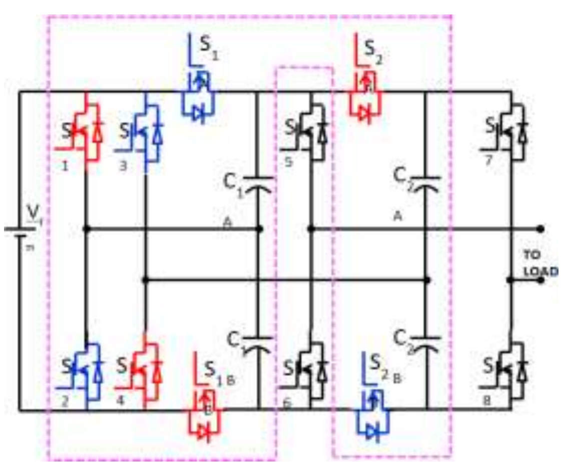


Fig 1. Proposed Inverter

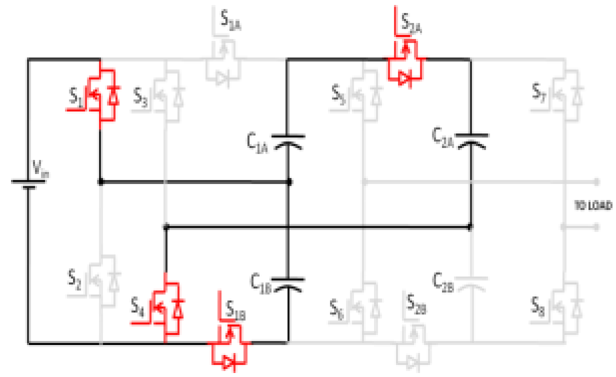


Fig 2(a)

Fig 2(b)

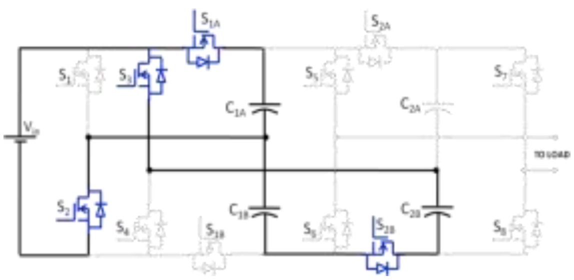


Fig 2 (a) Conduction Diagram for State A (b) ConductionDiagram for State B

There are five modes of operation of the proposed inverter to generated five levels. Operating modes of the proposed inverter are shown in figure 3 and explanations are given for each mode.

Mode 1: Figure 3(a) and figure 3(b) shows the mode 1 operation, in mode 1 S_P group switches and S_5 and S_7 switches are in ON condition and the other switches are in OFF condition. Output voltage across the load is 0 volts since the input voltage is not connected to the load. Capacitor C_1 and C_{2A} are in parallel to each other. Similarly when switches of S_N group and S_6 and S_8 are in ON condition a similar situation exists.

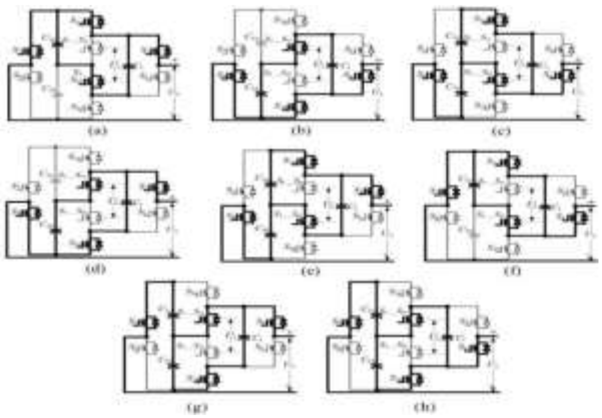


Fig 3. Modes of operation of the proposed inverter.

Mode 2: In Fig. 3(c) and 3(d), corresponds to mode 2, voltage value of $2V_{in}$can be obtained from theproposed converter. One operation state is that switches groupS_P, switches S_6, S_8 are turned ON and other switches are turnedOFF, capacitors C_1 and $C_{2a}$are in parallel connection,inverterhas the output voltage of C_{2b}, as shown in Fig. 3(c). Fig. 3(d)shows another operation statewith switches group S_N, switchesS_5, S_8 turned ON and other switches turned OFF, capacitors $C_1$and $C_{2b}$are in parallel connection, the inverter produces thevoltage of C_{2b}.

Mode 3: In Fig. 3(e), corresponds to the mode 3 operation in this, switchesgroup S_P, switches S_5, S_8 become on-state, capacitors C_1 and$C_{2a}$are parallel connection, the inverter outputs the summationvoltage of capacitor $C_{2a}$and C_2.

Mode 4: In Fig. 3(f) and 3(g) corresponds to the mode 4 operation, switchesgroup S_P, switches S_6, S_7 are turned ON and capacitors C_1 and$C_{2a}$are in parallel connection, the inverter outputs the reversevoltage of $C_{2A}$with value of $-V_{in}$. In Fig. 3(g), switches group S_N, switches S_5, S_7 conduct and capacitorsC_1 and $C_{2B}$are in parallel connection, the inverter outputs thereverse voltage of $C_{2A}$with value of $-2V_{in}$.

Mode 5: In Fig. 3(h), corresponds to mode 5 operation, switchgroup S_N, switches S_6, S_7 become on-state and capacitors $C_1$and $C_{2B}$are in parallel connection, the inverter produces the reverse voltage of $C_{2A}$and $C_{2B}$with value of $-4V_{in}$.

PERFORMANCE COMPARISION

The performance of the proposed inverter is compared in terms of active devices, diodes, capacitors, front end boost conversion, voltage stress, switching frequency, capacitor voltage balance control and number of DC sources with that of other similar type of inverters available in the literature. Table 1 shows a detailed comparison.

	Five Level Inverter			
	Diode Clamped	Capacitor Clamped	Cascaded H bridge	Proposed Inverter
Active Switches	8	8	8	12
Diodes	12	0	0	0
Capacit	4	10	2	4
Front End Boost Conversion	Needed	Needed	Needed	Not Needed
Voltage Stress	0.25 U_B	0.25 U_B	0.5 U_B	✓ 0.25 U_B (8 Nos) ✓ 0.5 U_B (2 Nos) ✓ U_B (2 Nos)
Switching Frequency	f_c	f_c	f_c	f_c (4 switches) f_l (4 switches)
Capacitor Voltage Balance Control	Difficult [9]	Difficult[10]	Difficult	Easy
Number of DC sources	1	1	2	1

Table 1: Performance Comparison

SWITCHING LOGIC

The switching logic of the proposed inverter is shown in figure 4. It has four level shifted carrier waveforms compared with the sinusoidal reference waveform.

From figure 4 it can be seen that four switches operates at low frequency which reduces the switching losses there by increasing the efficiency. Table 2 shows the switchinglogic of the proposed inverter in a simplified form.

Condition for Modulation and Carrier Wave		Switching States					
		S_P	S_N	S_5	S_6	S_7	S_8
$U_S >= U_C$	$U_S >= U_A$	1	0	1	0	0	1
	$U_S < U_A$	0	1				
$0 <= U_S < U_C$	$U_S >= U_B$	1	0	0	1	0	1
	$U_S < U_B$	0	1				
$-U_C <= U_S < 0$	$U_S >= U_C$	1	0	1	0	1	0
	$U_S < U_C$	0	1				
$U_S < -U_C$	$U_S >= U_D$	1	0	0	1	1	0
	$U_S < U_D$	0	1				

Table 2: Switching Logic of the proposed inverter.

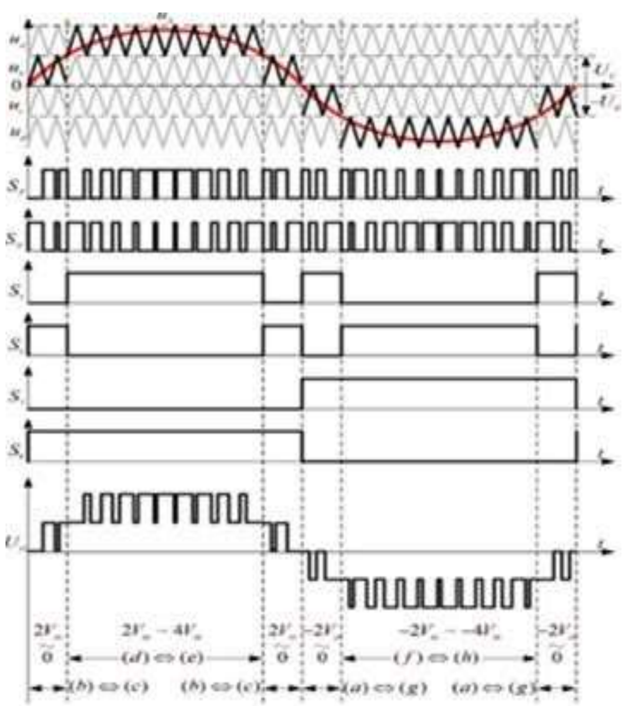


Figure 4 Switching logic of the proposed inverter.

SIMULATION RESULTS

MATLAB/SIMULINK software is used to simulate the suggested inverter, and the results are shown in this section. According to figure 5, the suggested inverter is fed by dc voltage of 100 V and the voltage is increased to around 400 V peak. The current delivered to the load by the suggested inverter is close to 30 A peak, as illustrated in figure 6, making it suitable for high power applications. The switching patterns of the SP and SN switches are displayed in Figure 7. The switching patterns of the switches S5 and S6 are similarly shown in Figure 8. Figure 9 displays the switching patterns of switches S7 and S8.

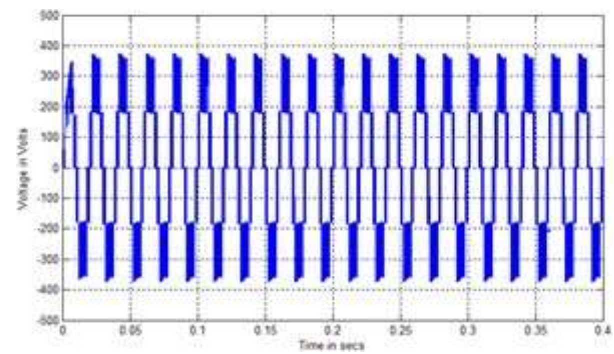


Fig 5. Load Voltage Waveform

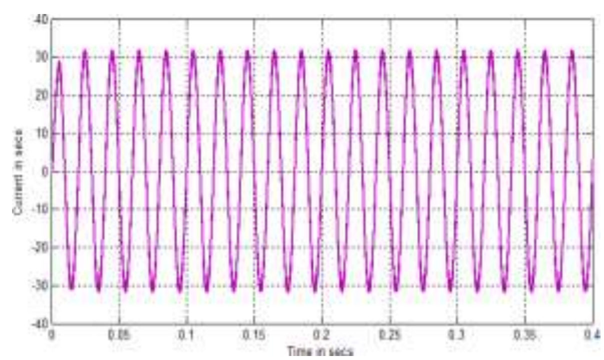


Fig 6. Load Current Waveform

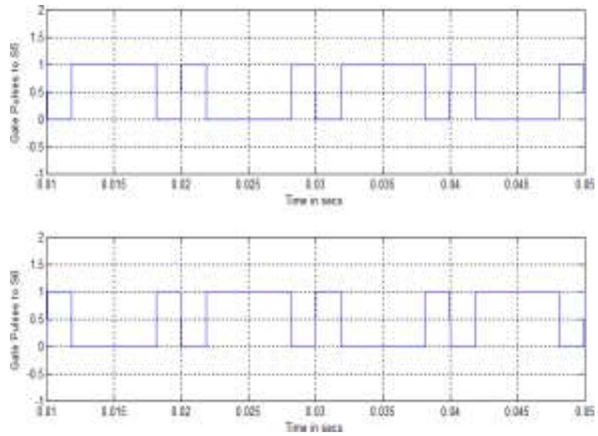


Fig 7 Switching pulses for S_P and S_N Switches.

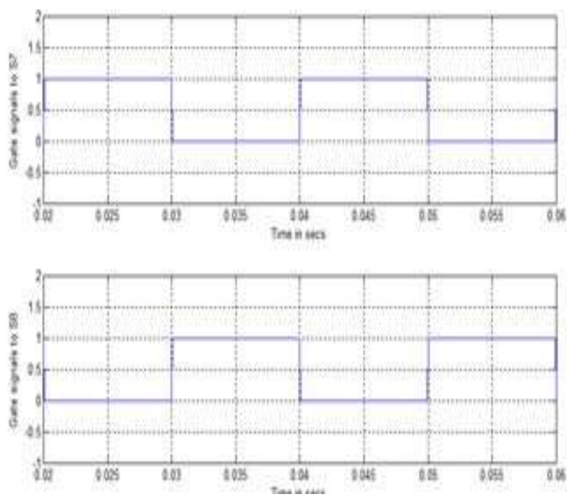
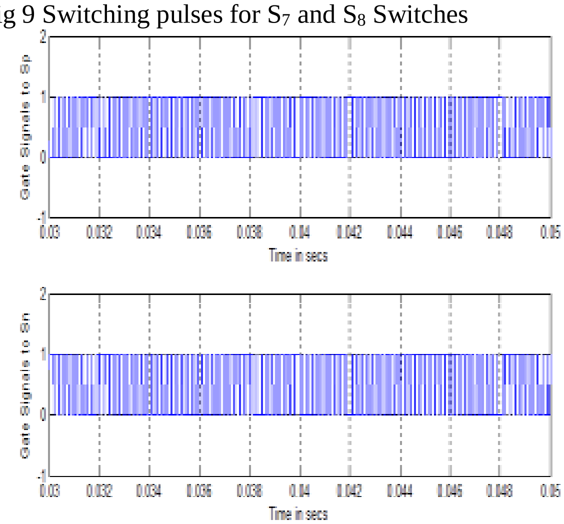


Fig 8Switching pulses for S_5 and S_6 Switches.

Fig 9 Switching pulses for S_7 and S_8 Switches



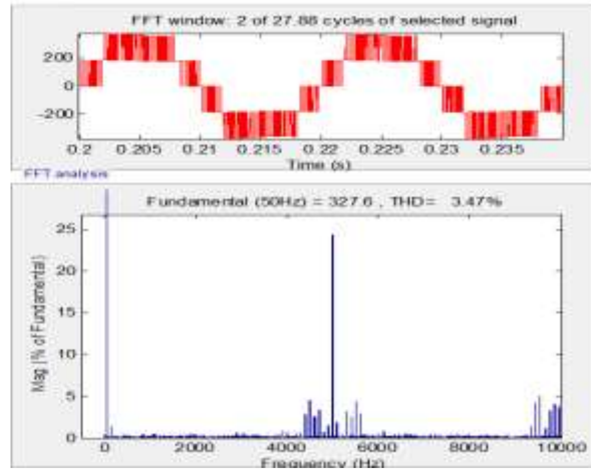


Fig 10 Output Voltage THD

Figure 10 displays the inverter's total harmonic distortion when it is working at full load. The proposed inverter's modulation index is adjusted from 0 to 1, and the inverter's performance is examined. It is discovered that when the modulation index is decreased, the number of levels drops to three. Figure 11 displays the voltage waveform with the lowered modulation index. The current waveform for a modulation index of 0.5 is shown in Figure 12. The total harmonic distortion is discovered to be less than 5%, which is the limit set by IEEE standards.

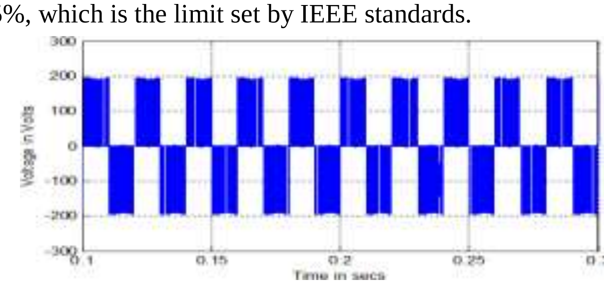


Fig 11 Load voltage with Modulation index = 0.5

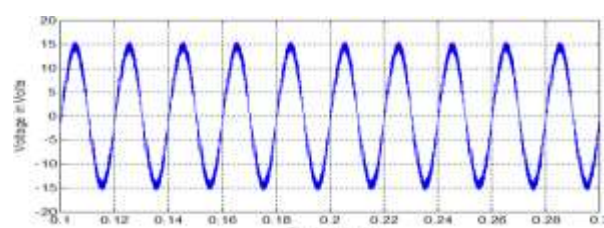


Fig 12 Load Current with Modulation index = 0.5

CONCLUSION

A brand-new single phase five level boost inverter that is appropriate for use with renewable energy sources is described. The suggested inverter's switches work at low frequency in some cases, which results in high efficiency operation. When compared to other inverters suggested in the literature, the suggested inverter requires the fewest switching devices. Results from simulations are shown for various modulation indices.

REFERENCES

1. Rodriguez, J., Lai, J. S., &Peng, F. Z. (2002). Multilevel inverters: a survey of topologies, controls, and applications. *IEEE Transactions on industrial electronics*, *49*(4), 724-738.
2. Venkatesan, M., Rajeswari, R., Kaliyamoorthy, M., &Srithar, M. (2017). Transient and Steady State Analysis of Modified Three Phase Multilevel Inverter for Photovoltaic System. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, *8*(1).
3. Ponnusamy, S. R., Subramaniam, M., Irudayaraj, G. C. R., &Mylsamy, K. An Improved Switching Topology for Single Phase Multilevel Inverter with Capacitor Voltage Balancing Technique.
4. Boopathy, C. P., &Kaliamoorthy, M. (2016). A Novel Asymmetrical Single-Phase Multilevel Inverter Suitable for Hybrid Renewable Energy Sources. *Circuits and Systems*, *7*(06), 932.
5. Boopathy, C. P., &Kaliamoorthy, M. (2016). A Modified Asymmetrical Single-Phase Multilevel Inverter Topology for Enhanced Power Quality. *Middle-East Journal of Scientific Research*, *24*(4), 1004-1015.
6. Venkatesan, M., Rajeshwari, R., Deverajan, N., &Kaliyamoorthy, M. (2016). Comparative Study of Three Phase Grid Connected Photovoltaic Inverter Using PI and Fuzzy Logic Controller with Switching LossesCalculation. *International Journal of Power Electronics and Drive Systems*, *7*(2), 543.
7. Raj, I. G. C., Kaliamoorthy, M., Rajasekaran, V., &Sekar, R. M. (2015). Single-Phase Cascaded Grid Connected Multilevel Inverter for Interfacing Renewable Energy Sources With Microgrid. *Journal of Solar Energy Engineering*, *137*(5), 051004.
8. Kaliamoorthy, M., Rajasekaran, V., Raj, I. G. C., & Raj, L. H. T. (2014). Generalised hybrid switching topology for a single-phase modular multilevel inverter. *IET PowerElectronics*, *7*(10), 2472-2485.+
9. Mylsamy, K., Vairamani, R., Irudayaraj, G. C. R., & Lawrence, H. T. R. (2014). Experimental validation of a cascaded single phase H-bridge inverter with a simplified switching algorithm. *Journal of Power Electronics*, *14*(3), 507-518.
10. Kaliamoorthy, M., Himavathi, S.,&Muthuramalingam, A. (2006, December). DSP based implementation of high performance flux estimators for speed sensorless induction motor drives using TMS320F2812. In *Power Electronics, 2006. IICPE 2006. India International Conference on* (pp. 104-109). IEEE.
11. Dr. M. Thangamani, Jafar Ali Ibrahim, Information Technology E-Service Management System, International Scientific Global Journal in Engineering Science and Applied Research (ISGJESAR). Vol.1. Issue 4, pp. 13-18, 2017. http://isgjesar.com/Papers/Volume1,Issue4/paper2.pdf

[12] Ibrahim, Mr S. Jafar Ali, K. Singaraj, P. Jebaroopan, and S. A. Sheikfareed. "Android Based Robot for Industrial Application." International Journal of Engineering Research & Technology 3, no. 3 (2014).

[13] Ibrahim, S. Jafar Ali, and M. Thangamani. "Momentous Innovations in the Prospective Method of Drug Development." In Proceedings of the 2018 International Conference on Digital Medicine and Image Processing, pp. 37-41. 2018.

[14] Ibrahim, S. Jafar Ali, and M. Thangamani. "Prediction of Novel Drugs and Diseases for Hepatocellular Carcinoma Based on Multi-Source Simulated Annealing Based Random Walk." Journal of medical systems 42, no. 10 (2018): 188. https://doi.org/10.1007/s10916-018-1038-yISSN 1311-8080, https://acadpubl.eu/hub/2018-119-16/1/94.pdf

[15] Jafar Ali Ibrahim. S, Mohamed Affir. A "Effective Scheduling of Jobs Using Reallocation of Resources Along With Best Fit Strategy and Priority", International Journal of Science Engineering and Advanced Technology(IJSEAT) – ISSN No: 2321- 6905, Vol.2, Issue.2, Feb-2014, http://www.ijseat.com/index.php/ijseat/article/view/62

[16] M. Thangamani, and Jafar Ali Ibrahim. S, "Knowledge Exploration in Image Text Data using Data Hiding Scheme," Lecture Notes in Engineering and Computer Science: Proceedings of The International MultiConference of Engineers and Computer Scientists 2018, 14-16 March, 2018, Hong Kong, pp352-357http://www.iaeng.org/publication/IMECS2018/IMECS2018_pp352-357.pdf

[17] M. Thangamani, and Jafar Ali Ibrahim. S, "Knowledge Exploration in Image Text Data using Data Hiding Scheme," Lecture Notes in Engineering and Computer Science: Proceedings of The International MultiConference of Engineers and Computer Scientists 2018, 14-16 March, 2018, Hong Kong, pp352-357http://www.iaeng.org/publication/IMECS2018/IMECS2018_pp352-357.pdf

[18] S. Jafar Ali Ibrahim and M. Thangamani. 2018. Momentous Innovations in the Prospective Method of Drug Development. In Proceedings of the 2018 International Conference on Digital Medicine and Image Processing (DMIP '18). Association for Computing Machinery, New York, NY, USA, 37–41. https://doi.org/10.1145/3299852.3299854

[19] S. Jafar Ali Ibrahim and Thangamani, M "Proliferators and Inhibitors Of Hepatocellular Carcinoma", International Journal of Pure and Applied Mathematics (IJPAM) Special Issue of Mathematical Modelling of Engineering ProblemsVol 119 Issue. 15. July 2018

[20] Thangamani, M., and S. Jafar Ali Ibrahim. "Ensemble Based Fuzzy with Particle Swarm Optimization Based Weighted Clustering (Efpso-Wc) and Gene Ontology for Microarray Gene Expression."In Proceedings of the 2018 International Conference on Digital Medicine and Image Processing, pp. 48-55. 2018. https://dl.acm.org/doi/abs/10.1145/3299852.3299866

[21] Dr.R.Chinnaiyan, Abishek Kumar (2017) " Reliability Assessment of Component Based Software Systems using Basis Path Testing" , IEEE International Conference on Intelligent Computing and Control Systems, ICICCS 2017, 512 – 517

[22] Dr.R.Chinnaiyan, AbishekKumar(2017) ,"Construction of Estimated Level Based Balanced Binary

Search Tree", 2017 IEEE International Conference on Electronics,Communication, and Aerospace Technology (ICECA 2017), 344 - 348, 978-1-5090-5686-6.

[23] R.Chinnaiyan, S.Somasundaram (2012) , Reliability Estimation Model for Software Components using CEP", International Journal of Mechanical and Industrial Engineering (IJMIE) , ISSN No.2231-6477, Volume-2, Issue-2, 2012, pp.89-93.

[24] R.Chinnaiyan, S. Somasundaram (2011) ,"An SMS based Failure Maintenance and Reliability Management of Component Based Software Systems", European Journal of Scientific Research, Vol. 59 Issue 1, 9/1/2011, pp.123 (cited in EBSCO, Impact Factor: 0.045)

[25] R.Chinnaiyan, S.Somasundaram(2011), "An Experimental Study on Reliability Estimation of GNU Compiler Components - A Review", International Journal of Computer Applications, Vol.25, No.3, July 2011, pp.13-16. (Impact Factor: 0.814)

[26] R.Chinnaiyan, S.Somasundaram(2010) "Evaluating the Reliability of Component Based Software Systems " ,International Journal of Quality and Reliability Management , Vol. 27, No. 1., pp. 78-88 (Impact Factor: 0.406)

[27] Dr.R.Chinnaiyan, AbishekKumar(2017), Estimation of Optimal Path in Wireless Sensor Networks based on Adjancy List, 2017 IEEE International Conference on Telecommunication,Power Analysis and Computing Techniques (ICTPACT2017) ,6,7,8th April 2017,IEEE 978-1-5090-3381-2.

[28] Ibrahim, S. Jafar Ali, and M. Thangamani. "Enhanced singular value decomposition for prediction of drugs and diseases with hepatocellular carcinoma based on multi-source bat algorithm based random walk." Measurement 141 (2019): 176-183. https://doi.org/10.1016/j.measurement.2019.02.056

[29] Compound feature generation and boosting model for cancer gene classification Ibrahim, S. Jafar Ali Ibrahim., Affir, A.M., Thangamani, M.International Journal of Engineering Trends and Technology, 2020, 68(10), pp. 48–51, Doi No:doi:10.14445/22315381/IJETT-V68I10P208 https://ijettjournal.org/Volume-68/Issue-10/IJETT-V68I10P208.pdf

[30] Innovative drug and disease prediction with dimensionality reduction and intelligence based random walk methods, Ibrahim, S.J.A., Thangamani, M.International Journal of Advanced Trends in Computer Science and Engineering, 2019, 8(4), pp. 1668–1673, https://www.warse.org/IJATCSE/static/pdf/file/ijatcse93842019.pdf

[31] R. Ganesan, M. Thangamani, S. Jafar Ali Ibrahim, "Recent Research Trends and Advancements in Computational Linguistics", International Journal of Psychosocial Rehabilitation Vol 24, no 8 (2020):1154-1162, DOI: 10.37200/IJPR/V24I8/PR280128

[32] C. Narmatha , Dr. M. Thangamani , S. Jafar Ali Ibrahim, " Research Scenario of Medical Data Mining Using Fuzzy and Graph theory", International Journal of Advanced Trends in Computer Science and Engineering, Vol 9, No 1 (2020): 349-355

[33] Dr.R.Chinnaiyan , R.Divya (2018), " Reliable AIBasedSmartSensorsforManagingIrrigationResources in Agriculture" , Lecture Notes on DataEngineeringandCommunicationsTechnologies,SpringerInternationalconferenceonComputerNetworksandInventiveCommunicationTechnologies(ICCNCT-2018),August2018

[34] Dr.R.Chinnaiyan,S.Balachandar(2018),"Reliable Digital Twin for Connected Footballer" ,LectureNotesonDataEngineeringandCommunicationsTechnologies,SpringerInternationalconferenceonComputerNetworksandInventiveCommunicationTechnologies(ICCNCT-2018),August 2018

[35] Dr.R.Chinnaiyan,S.Balachandar(2018),"Centralized Reliability and Security Management ofDatainInternetofThings(IoT)withRuleBuilder"LectureNotesonDataEngineeringandCommunicationsTechnologies,SpringerInternationalconferenceonComputerNetworksandInventiveCommunicationTechnologies(ICCNCT- 2018),August 2018(Online)

[36] Dr.R.Chinnaiyan,AbishekKumar(2017)"ReliabilityAssessmentofComponentBasedSoftware Systems using Basis Path Testing" , IEEEInternational Conference on Intelligent Computingand ControlSystems, ICICCS2017, 512– 517

[37] Dr.R.Chinnaiyan, AbishekKumar(2017,"Construction of Estimated Level Based BalancedBinarySearchTree",2017IEEEInternationalConferenceonElectronics,Communication,andAerospaceTechnology(ICECA2017),344 -348,978-1-5090-5686-6.

[38] Dr.R.Chinnaiyan, AbishekKumar(2017), Estimationof Optimal Path in Wireless Sensor Networks basedonAdjancyList,2017IEEEInternationalConference on Telecommunication,Power Analysisand Computing Techniques (ICTPACT2017) ,6,7,8thApril2017,IEEE978-1-5090-3381-2.

[39] Dr.R.Chinnaiyan,R.Divya(2017),"ReliabilityEvaluationofWirelessSensorNetworks",IEEEInternational Conference on Intelligent Computingand ControlSystems, ICICCS2017, 847– 852

[40] Dr.R.Chinnaiyan,Sabarmathi.G(2017),"InvestigationsonBigDataFeatures,ResearchChallengesandApplications",IEEEInternational Conference on Intelligent Computing and ControlSystems,ICICCS 2017, 782–786

[41] G.Sabarmathi,Dr.R.Chinnaiyan(2018),"Envisagationand AnalysisofMosquitoBorneFevers AHealthMonitoringSystembyEnvisagative Computing using Big Data Analytics"inICCBI2018–Springeron19.12.2018to20.12.2018(RecommendedforScopusIndexedPublicationIEEEXploredigital library)

[42] G.Sabarmathi,Dr.R.Chinnaiyan,ReliableDataMiningTasksandTechniquesforIndustrialApplications,IAETSDJOURNALFORADVANCEDRESEARCHINAPPLIEDSCIENCES, VOLUME 4, ISSUE 7, DEC/2017,PP-138-142,ISSN NO:2394-8442