Contribution to power conversion

Prof. Vukosavic made a significant theoretical and practical contribution to the design and construction of power converters, both electromechanical, including electric machines, and electrical-electric, including power electronics devices. With a simultaneous significant increase in the need for energy converters due to decarbonization, electrification of transport and significant growth of computer networks and data storage, the availability of mineral resources necessary for the construction of converters has become critical, partly due to limited planetary reserves, but also due to geopolitical changes that in the countries of Asia, Africa and South America make exploitation difficult. He was among the first to realize that, with the material expenditure invested in advanced digital hardware and corresponding software solutions are of a lesser importance, while the cost of the sensors, steel, copper and raw materials becomes ever more significant. He devised DSP-based solutions that increase the power-to-weight ratio, reduce the number of sensors and enable adaptive controls. Over the past three decades, prof. Vukosavic has offered a methodology for designing converters with minimal consumption of mineral resources, driven by the effort to save on magnetic circuits, power circuits, the mass of passive components and heat sinks through advanced optimization and control solutions.

Evidence

Power electronics devices are increasingly used in electrical grid and in power plants, where there is a need to build high-power and high-voltage converters, with the consumption of as few mineral resources as possible. In the field of electronic power converters that provide high voltage, and that use circuit resonance with L and C components, prof. Vukosavic proposed an original subresonant topology that significantly reduces the mass of passive LC components, increases specific power, and reduces the steepness of voltage and current changes in high voltage circuits. The theoretical foundations, design methodology and exploitation experiences are described in the paper [1]. The field test and the consequential applications were mostly related to coal-fired thermal power plants and their electrostatic precipitators. He also proposed original topologies for electromechanical power conversion [2], where the machine-converter integration and concurrent design and optimization of the asymmetrical switched reluctance motor and the corresponding electronic power converter offers considerable savings in overall mass and volume. Proposed topology of the SRM drive inverter keeps a low switch-count while solving the problems of demagnetization. It also extends the torque-speed range, as corroborated by experimental results. The sensorless SRM control algorithms, developed in the subsequent papers complete the control package and enable the possibility to use switched reluctance drives in a number of applications. In addition, he contributed to the development of multiphase machines and topologies, which increase reliability and reduce metal consumption. Multiphase electromechanical and power converters are increasingly used today in applications where operation must continue even in the event of a failure in one or two phases of the machine, or in the converter phases. The application of new topologies of electromechanical and electrical converters relies on appropriate control algorithms and on the integrity of the feedback signal acquisition in conditions of strong electromagnetic noise. In order to maintain the bandwidth and accuracy while suppressing the PWM and the EMI noise, prof. Vukosavic proposed [3] and deployed an original solution for the signal acquisition based on DMA-driven oversampling and filtering. He introduced a new methodology for the evaluation of variable parameters during operation [4], the correct knowledge of which allows the required energy conversion to be performed using converters of smaller volume and weight. He patented sensorless speed control of BLDC motors [5] which makes it possible to omit the installation of the encoder on the motor shaft, with significant savings in hardware and space.

Industrial impact

Methodology introduced by prof. Vukosavic in the field of electronic power converters for servo motor in multi-axis industrial robotics applications made a significant impact. One of the problems in motion control systems with large number of axes was a large number of individual inverters and drives with elevated weight, complex cabling and jeopardized reliability. Based on the aforementioned concept, several motor inverters, so-called servo amplifiers, were integrated into compact multi-axis modules DBM02, DBM03 and DMS2000, which contain several inverters. The integration of multiple inverter systems enabled a significant reduction in the volume and weight of the converter stages. At the same time, his work on subresonant power converter topologies enabled construction of light-weight high voltage sources and battery chargers. His work in the field of high-power multiphase converters and machines has a long lasting impact of increasing reliability, reducing the power-per-phase, introducing new degrees of freedom which facilitates advanced control performances and extending the use of mass-produced semiconductor power switches. Several journal papers and industry-applied projects with multiphase, multimotor drive systems provide the prime contribution to integrating the multiphase electrical machines with modular converter topologies and advanced controls, thus enhancing the flexibility and overall performance.

Evidence on industrial impact

Prof. Vukosavic has been applying his knowledge in the global industry, cooperating with Emerson-Electric on low cost, light weight electrical drives applied to household appliances and HVAC systems. Corresponding US patent is devised for and applied to brushless permanent motor drives, ensuring stable sensorless speed control of energy efficient permanent magnet motors, where it facilitates and simplifies extraction of the speed and position from terminal voltages and currents. Introduced in 1990, said method is nowadays widely used in household appliances and numerous other high-volume applications. Vickers Electric on the development of compact, modular multi-axis servo amplifiers with reduced mass and increased reliability; and with Moog-Electric on the development of a universal hardware platform of an electronic power converter that can be adapted to the needs of electric drives, solar sources, wind farms, battery chargers, regenerative rectifiers or static compensators through software changes. Prof. Vukosavic also cooperated with International Rectifier on introducing one of the first High Voltage Integrated Circuit (HVIC) solutions, and he himself designed the first HVIC demo kit IRADK10 suited for the needs of electronic controlled appliance drives. His extensive collaboration with numerous universities worldwide includes Liverpool John Moores, Northeastern, Virginia Tech, Imperial College, and others. His work shows a continuity spreading from the first breakthrough papers in the 1990's to the latest ones, and from the first industrial products in digital drives to the latest products in grid-side inverters and high-voltage power converters. His work in replacing analogue current controls for innermost loops by digital solutions with error-free-sampling system and the concept of integrated multi-axis drive were transformational. The first of the kind, Vickers-DBM series of multi-axis drives was introduced in 1992, providing a compact, robust and reliable solution for multi-axis applications. An equally significant step was introduction of his improved ac current controller with robustness against the noise in the feedback path and with advanced capability of harmonic suppression in MOOG-DM2020 and DW2020 line of inverters suited both for the grid-side inverters in renewable power sources and for the electrical drives. DBS and DS2000 industrial products were enhanced by prof. Vukosavic solutions for on-line parameter adaptation and efficiency optimization. Sensitivity of indirect rotor flux oriented controller is resolved by introducing an original, non-invasive adaptation mechanism which tracks the rotor time constant. Based on his original on-line identification of the loss function, he devised and deployed the loss-minimization algorithm which maximizes the efficiency of power conversion.

[1] S. N. Vukosavić, L. S. Perić and S. D. Sušić, "A Novel Power Converter Topology for Electrostatic Precipitators," in *IEEE Transactions on Power Electronics*, vol. 31, no. 1, pp. 152-164, Jan. 2016, doi: 10.1109/TPEL.2015.2405471.

[2] S. Vukosavic, V. R. Stefanovic, "SRM inverter topologies: A comparative evaluation," IEEE Trans. Ind. Appl., 27(6), pp.1034-1047, 1991.

[3] S. N. Vukosavic, Lj. S. Peric, E. Levi, "AC current controller with error-free feedback acquisition system," IEEE Trans. Energy Conversion, 31(1), pp.381-391, 2016.

[4] S. N. Vukosavic, M. R. Stojic, "On-line tuning of the rotor time constant for vector-controlled induction motor in position control applications," IEEE Trans. Ind. Electronics, 40(1), pp.130-138, 1993.

[5] S. N. Vukosavic, "Third harmonic commutation control system and method," USA Patent 4912378 (Utility), 1990.